

SCIENCE AND TECHNOLOGY

FOCUS

WHERE DOES
CONSCIOUSNESS
COME FROM?

WILL
ELECTRIC
CARS SAVE
OUR CITIES?

WHY THE
WORLD'S
RESOURCES
COULD LAST
FOREVER

+

THE
FUTURE OF
FIGHTING
CRIME

- AI detectives
- Predictive policing
- VR crime scenes

MATT RIDLEY ARGUES WHY OUR
PLANET'S FUTURE IS BRIGHTER
THAN YOU THINK

FIND OUT
HOW PAIN
WORKS

NEWLY DISCOVERED
MONSTERS
FROM THE DEEP

D7500

Nikon th 100 anniversary



I AM CHASING MOMENTS



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At the heart of the image

AUGUST 2017

WELCOME



To anyone taking a stock check of our planet's resources, the future doesn't look bright. Coal, gas and oil supplies are shrinking. Indium, nickel and tantalum – just some of the metals that go into our smartphones – are being used faster than we can dig them up. Food supplies and drinkable water are becoming strained as our planet's population swells and the climate changes. It's easy to imagine that the next century could be characterised by scarcity.

And that's without considering the ethical and ecological consequences of acquiring these precious resources. However, there is another way to look at this problem. On p36 Matt Ridley makes his case for a different future, one that's brighter than you might think.

Just one more thing... I'm a big crime fan. *Columbo's* more my flavour than *The Killing*; I love a great whodunnit. But the crime genre might be in trouble, as breakthroughs in the likes of genetics and AI are about to make solving crime a lot simpler. For instance, some cities are already working on systems that will help them predict crimes before they happen, much like earthquakes. And if someone does commit a crime, in the near future the police will probably be able to establish what the suspect looks like and what they've been up to from a few samples of blood and hair. There'll be no savant-like detectives either, as all the real work will be done by an artificial intelligence that's studied every criminal case from the last decade. Even then, unless they teach it to gather all its suspects into a room before delivering a lengthy monologue revealing the culprit, I suspect crime writers are going to have to shake up the genre. I jest, but the point stands that the way we fight crime is going through a revolution right now, turn to p48 for more.

Daniel Bennett, Editor

Daniel Bennett

IN THIS ISSUE



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IRENE TRACEY
Everybody hurts, sometimes. Irene Tracey, a neuroscientist at the University of Oxford, guides us through the science of pain. → p70

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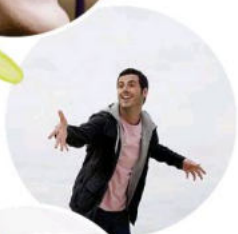
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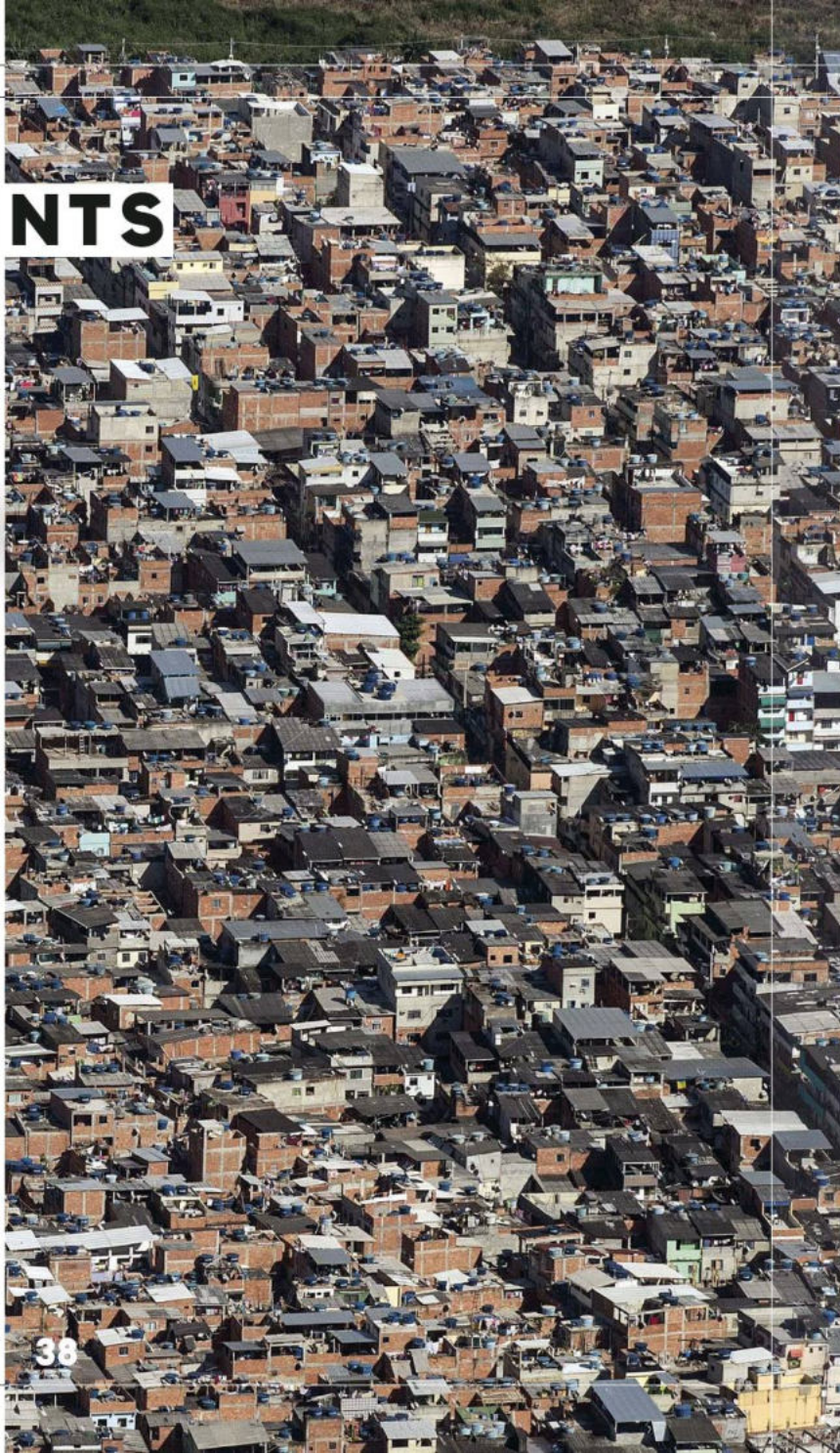
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Special issue



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EYE OPENER

Slippery customer

NAMIB DESERT,
NAMIBIA

If you find yourself wandering through the vast deserts of Namibia, watch where you put your feet! The Peringuey adder, also known as *Bitis peringueyi*, spends much of its time buried under the sand. As an ambush predator, the snake needs to remain unseen, and the sand provides the perfect camouflage.

Dr Brian Crother from Southeastern Louisiana University says: "The desert adder burrows into the sand, leaving its eyes, that sit on top of his head, and its black-tipped tail exposed. The black tail tip is gently waved about and used as a lure to bring lizards [its prey] within striking distance."

As a desert-dweller, the snake has a number of adaptations to survive in the harsh environment. First, it can travel using a form of locomotion called 'sidewinding', where just two points of its body are in contact with the sand at a time. This allows it to move quickly across loose terrain, and reduces contact with the hot sand. Second, water from morning fog condenses on its body, which it then drinks.

PHOTO: ALAMY





EYE OPENER

Swell snap

HAWAII,
USA

Photographer Sash Fitzsimmons claims he risked his life to take this incredible image. And physicist and oceanographer Dr Helen Czerski agrees that it's a dangerous business.

"The energy of a barrel wave like this one ultimately comes from the wind pushing the ocean surface into ripples and then up into bigger and bigger waves," she says. "As the water gets shallower, that energy is concentrated and the waves steepen until they break in these beautiful long barrels. One cubic metre of water weighs a tonne, so the rapid movement of this much water represents a huge amount of kinetic energy. Both the surfer and the photographers need superb judgment – and a bit of luck – to stay safe."

To take the picture, Fitzsimmons used a GoPro camera with a fisheye lens. It was fitted with a dome to push water away from the camera, allowing him to capture the action above and below the surface.

PHOTO: CATERS NEWS

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DISCOVERIES

DISPATCHES FROM THE CUTTING EDGE

AUGUST 2017

EDITED BY JASON GOODYER



Artist's impression
of Planet Ten

SPACE

IS THERE A TENTH PLANET?

Astronomers in the US have inferred the existence of an unknown 'planetary mass object' affecting the movements of space rocks in a distant asteroid belt

It seems the Solar System may be a little more crowded than we thought: a planet around the size of Mars could be hidden among its outer fringes.

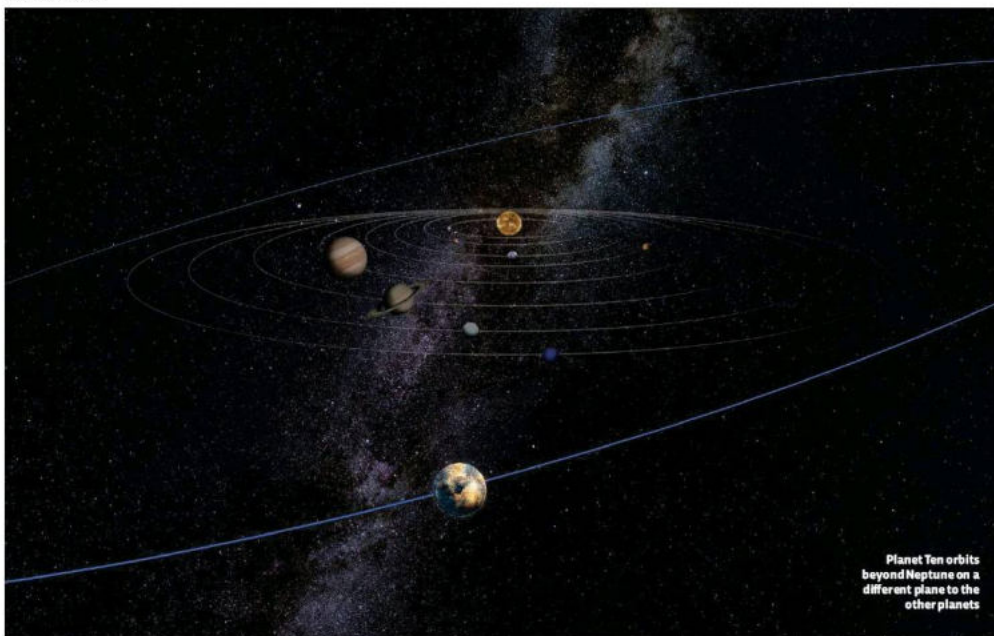
A team from the University of Arizona has discovered a mysterious mass, dubbed Planet Ten, that appears to be tugging at the orbits of a population of space rocks known as the Kuiper Belt in the icy outskirts of the Solar System.

The Kuiper Belt lies beyond the orbit of Neptune and

extends to a few hundred Astronomical Units (AU) with one AU representing the distance between Earth and the Sun.

The Earth and the other major planets all orbit the Sun in roughly the same plane. However, Kuiper Belt Objects (KBOs) are far enough away from the gravitational attraction of the gas giants to be tilted away from this plane, and are affected by interactions with one another.

PHOTO: HEATHER ROOPER/UPL



Planet Ten orbits beyond Neptune on a different plane to the other planets

This angle, known as the inclination, can be calculated. If the observed angle differs from the one calculated, then it's possible that the smaller KBOs are being pulled out of line by something more massive – potentially an undiscovered planet. This method is how the existence of the so-called Planet Nine was predicted last year.

After analysing more than 600 objects in the Kuiper Belt, the researchers found a discrepancy of 8° at around 50AU away from the Sun.

"The most likely explanation for our results is that there is some unseen mass," said researcher Kat Volk. "According to our calculations, something as massive as Mars would be needed to cause the warp that we measured."

The researchers say we may not have directly observed the planet because we haven't yet searched the entire sky for distant objects in the Solar System. However, a chance may come in 2020 when the Large Synoptic Survey Telescope (LSST) is completed.

"We expect LSST to bring the number of observed KBOs from currently about 2,000 to 40,000," researcher Renu Malhotra said. "There are a lot more KBOs out there – we just have not seen them yet. Some of them are too far and dim even for LSST to spot, but because the telescope will cover the sky much more comprehensively than current surveys, it should be able to detect this object, if it's out there."

"THE MOST
LIKELY
EXPLANATION
FOR OUR
RESULTS IS
THAT THERE
IS SOME
UNSEEN MASS"

EXPERT COMMENT

Colin Stuart

Astronomer and author

"All eyes are on the outer Solar System right now. First, astronomers found tantalising clues of a ninth planet beyond the orbit of Neptune. But now there might be a tenth, too.

We shouldn't really be surprised. The early Solar System was a much more chaotic place than the largely serene environment of today. Another planet is thought to have whacked into the Earth to form the Moon, for example. What's more, computer models of Solar System formation work better if there were more than four gas planets to begin with. Today's gas planets were the gravitational victors in the Solar System's childhood squabbles. Planets Nine and Ten, should they be confirmed, were likely bullied into far-flung orbits.

But why is it taking until now to find them? After all, we've found more than 4,000 planets beyond our Solar System. We don't spot those exoplanets directly – we look for changes in the light from their host stars to infer their presence. For us to see a distant planet in our own Solar System, light has to trek from the Sun all the way out there and back to the Earth, fading all the while. So they're on the edge of what we can see with current telescopes. With the potential Planet Ten, the task is even trickier due to its likely position close to the bright Milky Way.

Should the planets be found, more than a decade since Pluto was knocked off its planetary perch, the textbooks will need ripping up again."

PHOTOS: HEATHER ROPEL/LPL, NASA/JPL-CALTECH/SWR/MSSS/JASON MAJOR

MATHS

COMPUTATIONAL ORIGAMI TAKES A BIG LEAP FORWARD

An MIT professor of computer science and an assistant professor in civil engineering at the University of Tokyo have joined forces to come up with a better way of... making paper rabbits. Or rather, they have created an algorithm that enables the creation of any 3D shape from a single sheet of a given material.

MIT's Prof Erik Demaine has previous experience in this area: his 1999 PhD thesis described the same thing. The difference, though, is that his previous algorithm essentially involved taking a long, thin strip of paper or other material and winding it into the desired shape. This tends to leave you with lots of seams in the finished 3D shape, and is inefficient in terms of the amount of paper (or other material) required. The new algorithm, on the other hand, preserves the

boundaries of the original sheet of paper, and minimises the number of seams. "It's a totally different strategy for thinking about how to make a polyhedron," said Demaine.

If you've ever unfolded a paper cup from the water cooler, and ended up with a circular piece of paper, that's the perfect example of how the new algorithm works – the outer edge of the circle ends up as the rim of the cup. Demaine's old method, however, would have created a non-watertight cup shape by winding a thin strip of paper into a coil.

The technique could have practical applications in manufacturing, particularly in areas such as designing and building spacecraft, where materials efficiency is of paramount importance.



The new origami algorithm can make any shape from a single sheet of material

IN NUMBERS

1,203
KM

The distance Chinese researchers were able to successfully preserve quantum entanglement in a pair of photons – that's a new record.

66
MILLION

The numbers of trees planted by 15 million volunteers in Madhya Pradesh, India in 12 hours in an attempt to combat climate change.

5,100
SQUARE KM

The size of a giant iceberg that broke off an Antarctic ice shelf in the Weddell Sea. That's an area almost four times the size of greater London.



Volvo claims that by 2019 all its new vehicles will be electric or hybrid, like this XC90 model

PHOTOS: NEWSPIRE/GETTY

CAN ELECTRIC CARS SAVE OUR CITIES?

As Volvo announces plans to go all-electric by 2019, transport expert **Ian Walker** weighs up the environmental pros and cons

Volvo is the first major car company to announce that all its cars will soon have electric motors. None of its new models will rely solely on internal combustion after 2019, and other manufacturers are presumably not far behind. So what does this mean for the environment, and for our congested cities? Are electric cars really as eco-friendly as we're led to believe?

There is one area where electrification clearly brings an advantage, and that is exhaust emissions. Fumes from vehicles are implicated in around 40,000 premature UK deaths every year, with around 9,000 in London alone. Diesel fumes are a major issue here, although petrol is hardly benign. Vehicle emissions cause a host of unpleasant conditions, including cancer, heart disease, diabetes and Alzheimer's. Shifting to electric vehicles has the potential to change this dramatically, especially in urban areas.

There is also the possibility that electric cars, in the long term, might introduce a virtuous cycle of energy efficiency. Electric motors are not as heavy as their oil-powered ancestors, which means the overall vehicle can be lighter. In a country where most vehicles have become lighter, the damage from impacts is reduced. This means cars need less protective armour, which makes them even lighter, so they need even less energy to get around, which further reduces their damage, and so on...

Finally, there is the possibility of reduced carbon emissions, although this one is a bit less clear-cut. The carbon cost of electricity entirely depends on how it's generated. I'm writing this on an overcast, still day, and right now 49.4 per cent of UK electricity is from burning gas. Charging a car now would be far less green than charging it when it's sunny or windy. The greenness of electric vehicles, then, depends either on people's willingness to hold off charging them until conditions are good (which, based on some of our research at the University of Bath, looks unlikely) or a breakthrough in battery technology that allows energy to be stored efficiently from good days to bad days.



Head of Volvo
Hakan Samuelsson at
the announcement

"GOING ELECTRIC
WOULD DO
NOTHING TO REDUCE
CONGESTION"

Given their potential advantages – and the lack of urban pollution is one that's particularly appealing – it would be easy to become highly enthusiastic about electric cars. Many people already have. Governments might even be tempted to subsidise them to encourage a rapid uptake. But before we rush headlong into an electric future, it's important to consider any possible downsides too.

The main issue is that cars – both by their intrinsic design and by the way we use them – are associated with a broad range of problems that, at best, will be untouched by taking out a combustion engine and replacing it with an electric motor. Going electric would do nothing to reduce congestion – indeed, it could plausibly make it worse if pollutionless driving starts to feel 'guilt-free'. Electrification also fails to address the issue of where we store cars when they're not being used – and when you think about it, that's almost all the time.

There's also a host of issues that electrification, at best, addresses to such a marginal degree that it's hardly worth the bother. Take noise pollution. This is a far bigger public health problem than you would believe, contributing to conditions like hypertension, sleep disorders, and behavioural problems in children. But above even modest speeds, the noise from cars is mostly from the tyres, not the engine. Research we've carried out at Bath, with colleagues from Trinity College Dublin, showed that even if vehicles went 100 per cent electric overnight, the noise issue would be only very slightly reduced. Hardly a ringing endorsement.

But perhaps the greatest public health issue of our age is one that electrification completely fails to address: physical inactivity. The way we build and run our towns and cities means that it's easy, and socially acceptable, to drive short distances. At least a quarter of English car journeys are under two miles, usually taking up precious road space by carrying around several empty seats. These are journeys that in most cases would be quicker, cheaper and a great deal healthier and less congesting if walked or cycled. The guilt-free nature of electric cars could even make this slightly worse.

There are certainly advantages to a change like Volvo's, particularly when it comes to reducing urban pollution. But all we are being offered at the moment is the chance to replace cars' engines, not to look at the way we use cars in society. This means that we fail to work towards towns and cities that are truly healthier, safer and more welcoming, and we fail to free rural communities from their car dependence. There's a sense in which electric cars are old milk in new bottles. Really we should be asking far more fundamental questions about how and why we travel rather than just what sort of engines our cars have.

Dr Ian Walker is a psychologist at the University of Bath who specialises in traffic safety, transport choices and energy consumption.



Dave the cockatoo had been practising for his Counting Crows audition

ZOOLOGY

COCKATOOS GOT RHYTHM

Birds might generally be better known for their singing, but new research carried out by Prof Rob Heinsohn from the Australian National University (ANU) has proved they can also be a dab hand on the drums.

The palm cockatoo – also known as the goliath or great black cockatoo – is native to New Guinea and to Australia's Cape York Peninsula, an area of untamed wilderness in the far north of Queensland. It was here that Heinsohn's team were, for the first time, able to capture enough film of the reclusive species' drumming behaviour, which had previously been reported anecdotally, for serious study. The footage was obtained as part of a wider study into the bird's conservation needs.

Heinsohn and his team at the ANU Fenner

School of Environment and Society analysed seven years' worth of footage of 18 male cockatoos, and found that all 18 of the birds drummed regularly.

"The large smoky-grey parrots fashion thick sticks from branches, grip them with their feet and bang them on trunks and tree hollows, all the while displaying to females," said Heinsohn. "The icing on the cake is that the taps are almost perfectly spaced over very long sequences, just like a human drummer would do."

What's more, each cockatoo was found to have its own signature style, with some drumming faster or slower, and others introducing distinctive flourishes to the otherwise regular beat. It's thought that this enables other cockatoos to determine who is drumming where.

PHOTOS: C ZIENIEK, CHRISTINE DANLOFF/WIT ILLUSTRATION: DANIEL BRIGIT

SPACE

JUPITER'S GREAT RED SPOT CAPTURED IN UNPRECEDENTED DETAIL

NASA's Juno probe has delivered the goods yet again. This time, with photos of Jupiter's iconic Great Red Spot that were taken on 10 July.

The stunning images were pieced together by citizen scientists using raw data taken from the JunoCam as the probe passed just 3,500km above the planet's cloud tops – the closest any human-made object has come to the storm.

"I have been following the Juno mission since it launched," said citizen scientist Jason Major, who produced one of the images. "It is always exciting to see these new raw images of Jupiter as they arrive. But it is even more thrilling to take the raw images and turn them into something that people can appreciate. That is what I live for."

Measuring 16,350km across, Jupiter's Great Red Spot is a vast,

raging storm 1.3 times as wide as Earth. It has been under observation since 1830 and is believed to have existed for more than 350 years.

Early analysis of data taken by Juno portrays Jupiter as a highly turbulent world, with a complex interior structure, energetic polar auroras, and huge polar cyclones.

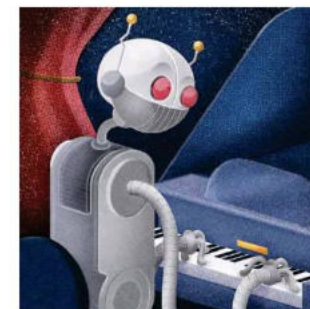
"For hundreds of years scientists have been observing, wondering and theorising about Jupiter's Great Red Spot," said Juno's principal investigator Scott Bolton. "Now we have the best pictures ever of this iconic storm. It will take us some time to analyse all the data from not only JunoCam, but Juno's eight science instruments, to shed some new light on the past, present and future of the Great Red Spot."

Juno's next close flyby of Jupiter will occur on 1 September.



Enhanced colour image of Jupiter's Great Red Spot

THEY DID WHAT?!



ROBOT TAUGHT TO COMPOSE MUSIC

What did they do?

Computer scientists at Georgia Institute of Technology in the US have taught a robot to compose its own musical pieces, and then play them on the marimba – an instrument similar to a xylophone.

How did they do that?

The robot – nicknamed 'Shimon' – was fed nearly 5,000 complete compositions, ranging from pop songs to classical pieces, and over two million smaller fragments such as riffs, solos and codas. Using deep learning techniques, its AI system then analysed the material and devised its own set of rules for composition. Using these rules, it then 'wrote' and played recognisably musical creations of its own.

Why did they do that?

Project leader Mason Bretan is interested in exploring the possibilities of AI and computer learning in music composition. Maybe the first robot masterpiece is just around the corner.

NEUROSCIENCE

"Video games are continually challenging our skills, making the brain perform at 100 per cent of its capacity"

Do video games change the brain? Different studies have reached different conclusions, so Marc Palaus, a neuroscientist at Spain's Universitat Oberta de Catalunya, reviewed the research

ABOVE: Do computer games make you more violent, or just more clever?

Do video games affect behaviour?

Video games are likely able to affect the way we behave in a number of ways. For instance, there's concern about whether violence in games makes young people more violent. It's not uncommon for news outlets to blame games every time a crime happens, but how true is that claim?

This is controversial even within the scientific community. Yes, exposure to violence seems to affect the brain, but studies have also found that we're good at distinguishing between real and virtual violence, and aggressive behaviour is better explained by other, mainly socio-economic factors. Numerous studies about the effects of games on the brain had been published, but all that information had not been put together until now.

How did you review the research?

We gathered all scientific articles to date and compared results. In total, we found 116 experiments, the first from the 1980s. Many compared regular video game players with people who had never played; others trained people in a game for several weeks and studied its effects. Changes in the brain were measured using magnetic resonance imaging (MRI) or

electroencephalography (EEG), which detect whether brain regions increase or reduce in size, and how it affects their activity.

Are games bad for the brain?

The clearest negative impact is the risk of abuse and addiction by people with predisposing personality traits. Video games can affect the reward circuits, containing the pleasure centres of the brain. This in turn could affect other brain functions in the frontal lobe, possibly affecting the capacity for planning, inhibiting distractions and mental problem-solving.

Games that heavily rely on online multiplayer modes are the most associated with addiction, due to social interactions being more rewarding than just playing against the computer.

Can games be good for you?

Since video games usually display increasing levels of difficulty, they are continually challenging our skills, making the brain perform at 100 per cent of its capacity, resulting in effective cognitive training.

Various mental functions seem to benefit from this effect. Of these, attention is the most

studied, and its enhancement allows us to better process objects in our visual field, selecting those which are relevant and ignoring the rest.

Attention improvements have a positive effect on 'executive functions', mental processes involved in controlling behaviour, solving problems and facilitating learning – functions that are closely linked to intelligence. Visuospatial skills – our capacity to process visual and spatial information – are also improved.

Can games be useful?

Video games contribute to the correct functioning of our brain, and can even improve it. So we have to get rid of our prejudices and accept them as valid entertainment. This also opens the door to using games as a form of training in clinical settings, especially for those with cognitive deficits.

BELOW: In some hospitals, video games are already used to help rehabilitate stroke patients



PHOTOS: GAMESPRESS/GETTY ILLUSTRATION: DAN BRIGHT



THE FORGETFUL

Do you often find it difficult to remember what you had for dinner last night? You might be a genius. Canadian researchers have found that jettisoning unimportant memories helps us to focus on the most important information.

COFFEE DRINKERS

Make mine a quadruple espresso! People who drink two to three cups of coffee a day are 18 per cent less likely to die from heart disease, cancer, stroke, diabetes and kidney disease, a team at the University of California has found.

GOOD MONTH

BAD MONTH

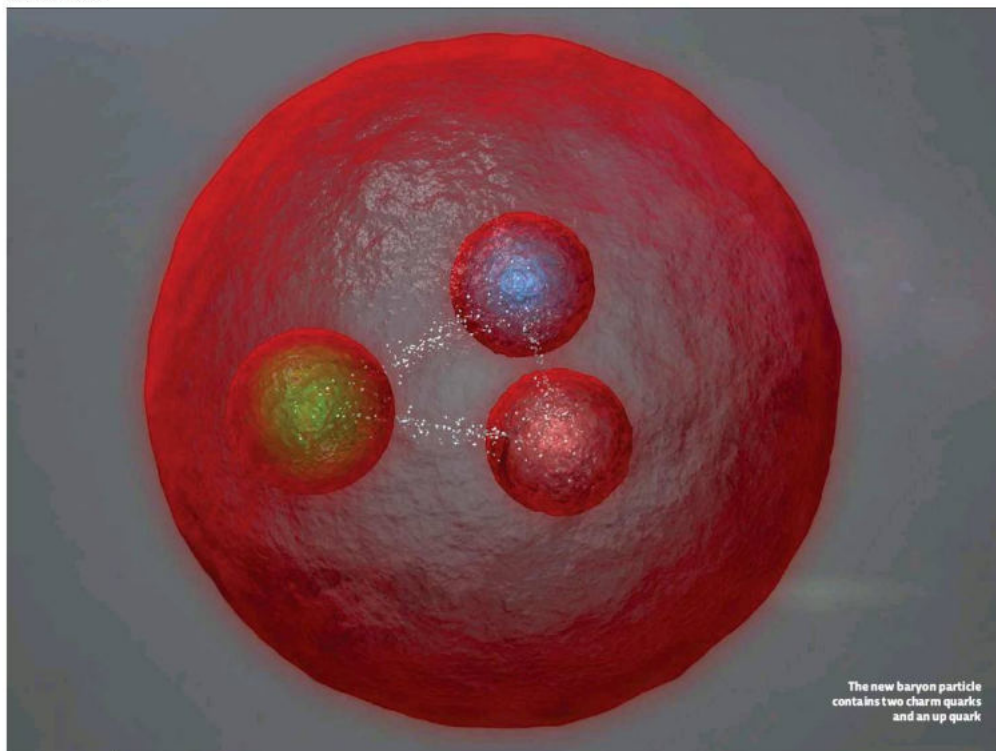
SMARTPHONE ADDICTS

If you break out in a sweat when your smartphone's out of reach, it may be time to rethink your habits. A University of Texas team has found that having a smart device in sight reduces our ability to focus and perform tasks.

TEENAGERS

So much for the vitality of youth! Researchers at the University of Baltimore have found the activity levels of the average 19-year-old are the same as those of people in their sixties.





The new baryon particle contains two charm quarks and an up quark

PHYSICS

NEW SUBATOMIC PARTICLE DISCOVERED AT CERN

What a charmer: scientists working at the Large Hadron Collider have found a new kind of subatomic particle. The particle is a baryon (a particle consisting of three quarks) named Xi-cc++, and is part of a family of 'doubly charmed baryons' whose existence had previously been predicted by the Standard Model of particle physics, but never observed. The research, led by University of Glasgow physicist Dr Patrick Spradlin, was carried out at the Large Hadron Collider's LHCb detector.

All the matter we see around us is comprised of protons and neutrons, which are baryons made of the lighter up and down quarks. Baryons that include the heavier charm, top, strange or beauty quarks decay almost instantly into protons and neutrons, making them hard to detect.

Many baryons have been observed with one heavy quark but Xi-cc++ is the first one that's ever

"FINDING A NEW HEAVY-QUARK BARYON IS OF GREAT INTEREST"

been seen with two heavy quarks—in this case two charm quarks.

"The properties of the newly discovered Xi-cc++ baryon shed light on a longstanding puzzle surrounding the experimental status of baryons containing two charm quarks, opening an exciting new branch of investigation for LHCb," said Spradlin. The new baryon is around 3.5 times heavier than a proton or neutron, and has an electric charge twice that of a proton. The Glasgow team discovered over 300 Xi-cc++ particles lurking in last year's LHCb data.

"Finding a new heavy-quark baryon is of great interest as it will provide a unique tool to further probe quantum chromodynamics, the theory that describes the strong interaction, one of the four fundamental forces," said researcher Giovanni Passaleva.

PHOTOS: CERN, GETTY

THINGS WE LEARNED THIS MONTH

MARS IS COVERED WITH TOXIC COMPOUNDS

The surface of the Red Planet is teeming with chemicals that could wipe out living organisms, say researchers from Edinburgh University. This finding greatly reduces the chances of finding life on Mars.

OUR BRAINS BENEFIT FROM PHYSICAL EXERCISE

Working out can be just as beneficial for our brains as our bodies. A team at the University of Arizona has found that taking exercise leads to improvements in brain structure and function—an effect thought to be linked to our evolution from sedentary apes to active hunter-gatherers.

CHILDREN WHO SLEEP LESS COULD AGE FASTER

Telomeres are structures at the end of our chromosomes that shorten with age. In nine-year-old children who miss out on sleep, they are significantly shorter than in kids who sleep more, a study at Princeton University has found.

EARTH IS ON THE BRINK OF MASS EXTINCTION

Over the last century, Earth has undergone a decline in mammal populations akin to 'biological annihilation', according to Mexican researchers. This is due to human overconsumption and overpopulation, they say.

NEUROSCIENCE

'LEARNING WINDOW' FOR LANGUAGES AND MUSIC EXTENDED USING SINGLE BRAIN CHEMICAL



Children are better at learning instruments and languages than older people, but scientists may have unlocked a way to extend this capability to adults

If you want your child to become fluent in foreign languages, or grow up to be a concert pianist, then the advice has always been to start them as early as possible. There's a sound scientific reason for this: children have a much greater capability for auditory learning than adults. But now, in news that will delight pushy parents everywhere, researchers at St Jude's Children's Research Hospital in Memphis, Tennessee have managed to extend this 'learning window' into early adulthood, albeit only in mice so far.

The researchers used several different techniques to either reduce the brain's supply of the neuromodulator adenosine, or block the A1 receptor that is vital to its function. Adenosine inhibits the release of the neurotransmitter glutamate, which is used by the auditory

thalamus and the auditory cortex, the areas of the brain that process sound. With adenosine production and activity suppressed, the auditory thalamus and cortex had more glutamate to work with. As a result, the adult mice with lower levels of adenosine exhibited a greater ability to differentiate between tones than adult mice in the control group.

"These results offer a promising strategy to extend the same window in humans to acquire language or music ability... possibly by developing drugs that selectively block adenosine activity," said research lead Dr Stanislav Zakharenko.

Be warned, though. Adenosine is also involved with sleep and suppressing arousal. So, if your virtuoso violinist grows up to be an insomniac sex maniac, don't come crying to us...



PREDICTING THE UNPREDICTABLE

It's the end of the world as we know it, again. And I feel fine...

Ten years ago this month, an event took place in Paris which signalled the start of EOTWAWKI. No, it's not a Maori festival; it's something much less fun: The End Of The World As We Know It.

In August 2007, a French investment bank told some of its clients they couldn't get access to £1bn of their own money. While undoubtedly bad news for those involved, it didn't seem like a huge story for the rest of us. But what happened on that Thursday afternoon is now widely seen as the start of the Global Financial Crisis.

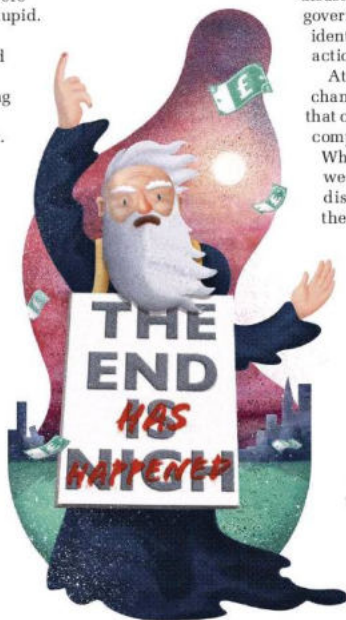
Over the following year, trillions of pounds of wealth evaporated, global financial institutions went bust and the world's economy teetered on the brink. The cause was the discovery that vast financial bets had been made by banks about the health of US housing market. Bets that were complex, interconnected and, frankly, stupid. And when they started to go wrong, the consequences went global – and changed the world forever.

Now there's talk of EOTWAWKI coming around again. This time, it's soaring consumer debt that's prompting concern. From car loans to credit cards, levels of debt are soaring again.

So, is The End nigh – again? Unlikely. Sure, there are lots of pundits predicting it, but then there always are. What they've missed is the fact that we really did experience EOTWAWKI in 2007. Not the end of the world as in Armageddon, but literally the end of the world as we used to know it.

Back then, many experts thought it was possible to make predictions about, say, the US housing market, and make bets – and money – accordingly. Some even thought they could tell when the economy was in trouble. Not any more. Now, financial regulators and central banks are far more sceptical about economic forecasts and the reliability of financial models. Most have come to accept that another crisis

**"WE MAY BE
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OF LIFE IN A
COMPLEX
WORLD"**



is pretty much certain, but that it's also pretty much certain that no one can say with any degree of confidence when it will strike.

So, regulators now insist that banks keep a greater chunk of their wealth sitting in their vaults for when the inevitable happens. They also have to undergo regular 'stress tests' which simulate the impact of severe downturns. A close eye is also kept on smart-aleck bets of the kind that caused mayhem a decade ago.

None of this is guaranteed to stop a repeat of 2007, but it does reduce the risk. And when it comes to dealing with uncertainty, that's as good as it gets. It's an attitude that's gaining traction elsewhere – and not before time. After spending decades and billions trying to predict natural disasters like droughts, storms and earthquakes, governments are increasingly focusing on identifying the high-risk areas, and taking action ahead of time.

Attitudes to global warming are also changing. Despite decades of effort, it's clear that climate models still struggle with the complexity of predicting the future in detail. What is clear is that we can't carry on the way we are, and must act now to reduce the risk of disaster. That's a truth that is recognised in the much-maligned Paris climate accord, which calls not only for reductions in greenhouse emissions, but also efforts to adapt to a warmer world.

We may be witnessing a revolution in the way humanity deals with the inevitable uncertainties of life in a complex world. Prediction is giving way to adaptation. If so, it's a case of back to the future. Our knuckle-grazing ancestors never kidded themselves they knew what the future held. They just adapted to whatever their gods hurled their way, from floods to Ice Ages. It's taken us 10,000 years to realise they were right.

Still, better late than never. **o**

Robert Matthews is visiting professor in science at Aston University, Birmingham.

ILLUSTRATION: DANIEL BRIGHT



Dr Saunders strikes back

Psychiatrist suffers stroke, then analyses symptoms to help others

Dr Tony Saunders always looked after his health, so it seemed doubly unfair when he collapsed with a major stroke in the gym.

Tony's family were worried that he could die, as stroke takes a life every 13 minutes in the UK. And it's the leading cause of severe adult disability.

Fortunately, with excellent treatment, Tony eventually returned to work.

But Tony noticed that discussing his stroke made him anxious – he even started stuttering.

As a psychiatrist, he identified this as post-traumatic stress disorder. He then realised that, on top of his medical training, he now had valuable first-hand experience of stroke.

So Tony struck back by overcoming his anxiety, and giving talks to medical students. As a result,

a new generation of doctors are supporting their patients with powerful new techniques.

This is Tony's legacy. And now you can strike back against stroke too, by leaving us a legacy of your own.

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INNOVATIONS

PREPARE YOURSELF FOR TOMORROW

AUGUST 2017

EDITED BY RUSSELL DEEKS



MEAN MACHINE

To kick off the 'Summer of Mars' events programme at the Kennedy Space Center in Florida, NASA recently unveiled an 8.5m-long concept Martian rover that wouldn't look out of place in the Batcave.

The vehicle consists of a detachable rear section housing a science laboratory, and a front section that's

equipped with radio and GPS. Sadly it is only a concept: according to the latest information on NASA's website, the actual rover used in the Mars 2020 mission is likely to be similar in size and appearance to Curiosity, the 3m-long rover that's been busy exploring the Red Planet's surface since 2012.

PHOTO: NASA

1



2



3



4



5



6



WANTED

1 SEAWEED SNEAKERS

These eco-friendly, amphibious trainers from Vivobarefoot and Bloom Foam are made entirely from reconstituted algal biomass, which is harvested from waterways that have a high risk of harmful algal blooms. Better than jelly shoes, any day!

Vivobarefoot Ultra III
ETBC, vivobarefoot.com

2 NINTENDO NOSTALGIA

The SNES is back! Available from 29 September, the SNES Classic Mini is smaller than the original and eschews the cartridges, coming instead with 21 preloaded games including *Super Mario Kart* and *The Legend Of Zelda*. Nostalgic fun awaits.

SNES Classic Mini
£69.99, nintendo.com

3 TINY TOUCH, BIG SCREEN

Sony's ultra-compact Xperia Touch projector sends an 80cm 'touchscreen' onto virtually any flat surface, and runs on Android so you don't even have to use a laptop with it – though it has an HDMI input if you need it.

Sony Xperia Touch
£1,300, sony.com

4 SUPER SPIDER-MAN

Sphero's new IoT-enabled Spider-Man toy will let kids tag along on missions to battle villains – every choice they make influences the adventure. And unless he's installing updates, Spidey stays offline, so he's safe from snoopers.

Spider-Man Interactive Super Hero,
£150, sphero.com

5 KEEP IT PURE

If privacy and security are concerns for you, then Purism's Librem 13 or Librem 15 could be just the laptop you're looking for. It has a bespoke, security-focused Linux operating system, and kill switches for Wi-Fi, Bluetooth, mic and camera.

Purism Librem laptops
From \$1,699 (£1,300 approx), puri.sm

6 MARQUIS DE SOUND

The contraption may look like an exhibit from Scotland Yard's infamous Black Museum but it's actually a headphone amp. It's the perfect gift for the death metal lover who has everything. But at £6,000, it ain't cheap!

Metaxas & Sins Marquis
£6,000, metaxas.com

ON THE ROAD TO SMART CARS

With 3D scanning, gesture control and a touchscreen key, is BMW's new 5 series the smartest connected car yet?

BMW 5 SERIES 530D XDRIVE

PRICE: FROM
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PACKAGE: £1,405

REMOTE CONTROL
PARKING: £395

DRIVING ASSISTS:
£2,250

SPEC:

ENGINE: 3.0L DIESEL

POWER: 265BHP
@ 4,000RPM

GEARBOX: 8-SPEED
AUTOMATIC

OFFICIAL MPG: 53.2

CO₂ EMISSIONS:
138G/KM



TECHNOLOGY

Before we get to the car, we need to talk about the key. It's a touchscreen remote that lets you check the car's fuel tank, turn on the air conditioning, and if you really want to show off, remotely park or pull out of a spot while you're stood on the pavement. Park the car from behind the wheel, and sensors and cameras bring up a reactive view of the car on the 10.25-inch touchscreen. Pull up to a wall, and the screen switches to a top-down view to show you closing the gap. Parallel park and the camera pans to a corner view compiled from a couple of cameras. The tech itself isn't new, but the way it adapts to the current situation feels telepathic. There's more wizardry found in the car's gesture control tech, borrowed from the 7 series, which lets you skip tracks or turn up the volume by waving your hand in the air.

CONNECTIVITY

First off, the iDrive system is brilliant. It's instant. Unlike many in-car entertainment systems there's no delay between input and response. The new 5 series tech package also offers Apple Carplay without wires via Bluetooth – the first car to do so. But to really unlock the car's box of tricks you have to get an app, BMW Connected. You can sync your Office 365 calendar to the car's database and it'll tell you when to leave to make a 9am meeting. But here's the real showstopper. If you lose your car in the car park, the app will get the car to scan its environment, using the radar and cameras used for self-parking, to create a picture of its surroundings. Luckily a bright yellow van had pulled up alongside the car, so from there it was easy to spot. Yes, it's a bit frivolous, but the idea is an astonishing way to pull together the tech that's already in the car.



DRIVE

For the most part we let the 5 series pilot itself (with our hands on the wheel, of course). The lane assist and cruise control functions let the car do most of the actual driving on the motorways. And after driving nearly 500km (more than 300 miles), I felt confident that the car could spot hazards before me. Off the motorway it's a fiercely capable all-rounder. The suspension is soft and supple, but can be stiffened for B-road meandering. Our 530d with four-wheel drive was leisurely when needed, but had the option of 620Nm of torque to take you from 0-60 in 5.4 seconds. In adaptive mode, the car will tweak the suspension according to your steering input and what corners it can see on the GPS. Ultimately it's a car that can lower your heart rate as well as raise it.



VERDICT

This is the most well-rounded car we've driven. It feels like a yacht on the motorway, and a speedboat on the B roads. Above all, we were most impressed with the tech inside. The ubiquity of smartphones means our expectation of how simple and responsive technology should be is stratospherically high. In-car tech usually suffers from this comparison, feeling sluggish and unresponsive next to our smartphones. But the 5 series subverts that trend. Whether you're using the self-parking, driving assists or the connected app, everything is effortless, making it the saloon to beat right now. **9/10**

ENVIRONMENT

NEVER MIND THE PESTICIDES, HERE'S A BUG-ZAPPING FENCE!

Farmers under pressure to reduce chemical pesticides can take heart from the news that the US Department of Agriculture is about to start trialling a device that can kill insects with a laser.

Developed by Seattle company Intellectual Ventures Lab (IVL), the 'Photonic Fence' isn't really a fence at all, but a small box containing lasers, cameras and an AI computer system. The cameras scan the air around the device for 100 metres, and the AI system measures the shape, speed, acceleration and wingbeat frequency of any bugs detected, to establish which are potentially harmful. Any insects identified as a threat can then be zapped by the lasers, with a 'kill rate' of up to 20 insects per second.

By deploying several such devices, farmers could effectively create a virtual fence around their crops that kills harmful pests but leaves bees and other beneficial or harmless insects unharmed.

As well as protecting crops, it's hoped the Photonic Fence could also prove useful in the fight against malaria, by eliminating only the *Anopheles* mosquitoes that spread the disease without upsetting the balance of the local ecosystem in the way that blanket use of chemical pesticides would.

The US trials will begin in August. If the device is proven to work, then IVL hopes to bring a commercial product to market, though that will still be some years away.



PHOTOS: I.V. HYPERLOOP



TRANSPORT

HYPERLOOP FOR THE UK?

Hyperloop One has announced its Vision For Europe – a series of proposed routes for Hyperloop transportation systems in mainland Europe and the UK.

First proposed by Elon Musk in 2012, Hyperloop is a hybrid electric/maglev system designed to shift people and cargo long distances at very high speeds, by placing them in pressurised pods that travel through tubes in which a partial vacuum is maintained. There are several companies and teams of scientists and engineers working worldwide to develop Hyperloop systems, including Hyperloop One, Hyperloop Transport Technologies and TransPod.

Citing the success of Eurostar trains in capturing 70 per cent of cross-Channel traffic in just a few years, Hyperloop's Vision For Europe proposes routes linking Corsica to Sardinia, Spain to Morocco, and Estonia to Finland. There are also suggested routes in Germany, Poland and the Netherlands, plus three in the UK.

One of these routes would link Cardiff and Glasgow, via Bristol, Oxford, London, Cambridge, Nottingham, Newcastle and Edinburgh. For this route, Hyperloop One has been working with engineering firm AECOM. A second route, dubbed the Northern Arc, has been proposed in association with architects Ryder and engineering firm Arup, and would link Liverpool to Glasgow via Manchester, Leeds, Newcastle and Edinburgh. Finally, the North-South Connector route, which has been developed in association with students and faculty at the University of Edinburgh and Heriot-Watt University, would link London and Edinburgh via Manchester and Birmingham.

All three of the routes are, it should be stressed, strictly speculative propositions at this stage. But the fact that so many leading businesses and academic institutions around the world are taking the Hyperloop project seriously suggests it may become a reality sooner than we think.

TECH BYTES

CODING FOR GIRL SCOUTS

Girl Scouts in the US can now earn badges for coding, hacking and cybersecurity awareness. The new badges have been introduced in a bid to encourage more young women to pursue careers in the IT sector.



CITIZENS OF SPACE

Asgardia, a 'virtual nation' set up by a Russian scientist last year, already has some 200,000 citizens. And now it's launching its own small satellite where all those citizens' data will be stored, along with Asgardia's flag, constitution and 13-month calendar.

TEMPERANCE TAG

Police in Lincolnshire are trialling a leg-mounted tag that, instead of tracking the movements of low-level offenders, monitors their alcohol intake. It's designed to ensure offenders stick to booze-free conditions imposed as part of a community sentence.



HEALTH

A HEADBAND TO TREAT DEPRESSION?

A South Korean biomedical start-up called Ybrain has developed a headband that they claim will offer relief from the symptoms of depression. The device, called Mindd, works using a technique called transcranial direct-current stimulation (tDCS). Here, a low-voltage electrical current is applied to specific areas in the brain via electrodes placed on the skull.

tDCS is not new – the basic principles have been understood since the early 19th Century. But the past decade or so has seen increased interest in its use in treating neurological and psychiatric conditions, and a 2016 meta-analysis of hundreds of studies concluded that it's "possible or probably effective" as a treatment for depression.

tDCS equipment can stimulate

particular brain regions either 'anodally' (increasing neuronal activity) or 'cathodally' (decreasing neuronal activity). The Mindd headband applies anodal stimulation via electrodes in the headband to the frontal lobe, an area where decreased activity is associated with depressive disorders. Mindd is not intended as a DIY solution: patients would use it in their own homes, and all data regarding treatment would be sent automatically to their doctor.

The headband is currently undergoing clinical trials at Harvard Medical School, and at 12 hospitals in South Korea. Early results are said to be promising, and if all goes well Ybrain hopes to market the device to health providers by 2019.

AVIATION

HELICOPTERS: NOW WITH WINGS!

At the recent Paris Air Show, Airbus was showing off its new Racer concept helicopter, which has both a main rotor and a pair of propeller-sporting wings. Racer (an acronym for 'Rapid and Cost-Effective Rotorcraft') would take off and land vertically, just like a normal helicopter, but would boast a top speed of 400km/h (250mph), which is nippier than traditional choppers. If you're getting a sense of déjà vu here, that's because the Racer is essentially an updated take on the X³ concept that Eurocopter (now Airbus) took to the Paris Air Show in 2011.

The craft is designed for the operation of high-speed passenger services, particularly between urban centres (such as London and Berlin) where its vertical take-off and landing capabilities eliminate the need to travel to and from airports. But it could also find a role in military or search-and-rescue operations. Airbus hopes to have a commercial craft based on the Racer concept available by 2020.



PHOTOS: YBRAIN, AIRBUS



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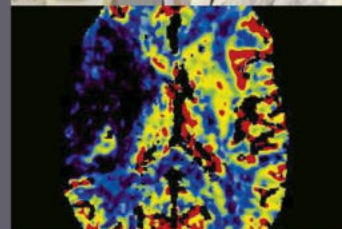
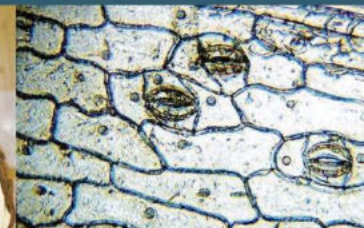
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MESSAGE OF THE MONTH

Brushing up

I was fascinated by your article about the work of Prof Richard Muller on the origins of time (May, p38). I like the idea that time is made as a series of 'nows', as space-time expands following the Big Bang. With new space, new time has to also come into being. It occurred to me, though, that there might not be any reason for each new 'now' to be the same size as the last one.

This would have a bearing on the current work on dark energy and the apparent acceleration of the expansion of the Universe. If, as space expanded, the successive 'nows' were actually becoming very slightly smaller over aeons, then the expansion of the Universe might not actually be speeding up, but only appear to be. Objects moving at a steady speed through successively smaller chunks of time would appear to be accelerating.

Do we need dark energy to explain this, or could it just be an artefact of the creation of time itself?
 Tim Curthew-Sanders, London

☛ Your idea that time is not only created, as Prof Muller suggests, but also in variable amounts is intriguing, but I suspect many theorists will see it as a complication too far – at this stage, at least. Over the years, the idea of allowing fundamental properties of the Universe like dark energy, the strength of gravity and the speed of light to vary with time has been studied, but to no real benefit. – Prof Robert Matthews, BBC Focus science consultant

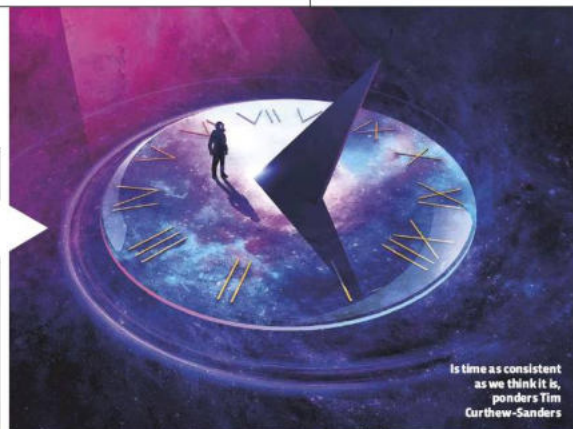
WRITE IN AND WIN!

The writer of next issue's *Message of the Month* wins an **Health Wireless Blood Pressure Wrist Monitor**. This system, consisting of a wristband and accompanying Android/iOS app, will let you measure and track your own blood pressure at home, without needing to bother your GP.



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Is time as consistent as we think it is, ponders Tim Curthew-Sanders

On the flipside

In a recent 'Q&A' (Summer, p86) you answered a question by Coco Shang that indicates that work was still going on into the reason for toast to usually land butter-side down on being dropped.

This is an old chestnut, and surely any school boy will tell you that the usual reason for this occurrence is that the toast was probably buttered on the wrong side in the first place.

Peter Duckworth, Ceredigion

Re: the 'Q&A' question about toast, I recommend ALL scientists to read the excellent book *Eureka's And Euphorias* by Walter Gratzer. On page 45, he describes a US scientist investigating this very problem, who found his children's toast

always fell butter-side up. He only discovered later that his children buttered BOTH sides of their toast!
 Stuart Ching, via email

Trying tyres

Helen Czerski presents us with an interesting puzzle in her latest column (Summer, p76). May I suggest the following explanation?

From her description, the nail seems to have entered through the thicker, treaded part of the tyre, and then pierced the thinner sidewall, next to the rim.

When first entering the tyre, the nail would drag after it a cone of stretched rubber from the inner tube, as Helen suggests – a skirt around the nail. On exiting the other side, the nail would not be able to deform the



No tyres were harmed in the taking of this picture

PHOTOS: ANDY POTTS; BANA LOCKE/GETTY

inner tube to the same extent, as it would be supported by the outer casing. Also the nail would not travel as far through the exit hole as it had through the entry hole.

Once the head of the nail was flush with the tyre tread and the wheel rolled forward, the nail would be drawn back out very slightly due to the skirt at the entry point being greater, and therefore stronger, than that at the exit point. This would result in a small internal rubber skirt at the exit point but there would still be enough of the internal skirt at the entry point to maintain the seal.

During the remainder of the journey, every time the nail head hit the ground it would be pressed in flush again but would immediately pop back out. The movement would be very small, especially with high pressure in the tyre, and deformation at the point of road contact would be minimal. It appears this very slight movement was not enough to cause the seals to fail although, as Helen says, you have to wonder

Our piece on research into sleeping trees (July 2016) went down well with the research team involved

how much farther (not further!) it would have held up.
 John Pawson, via email

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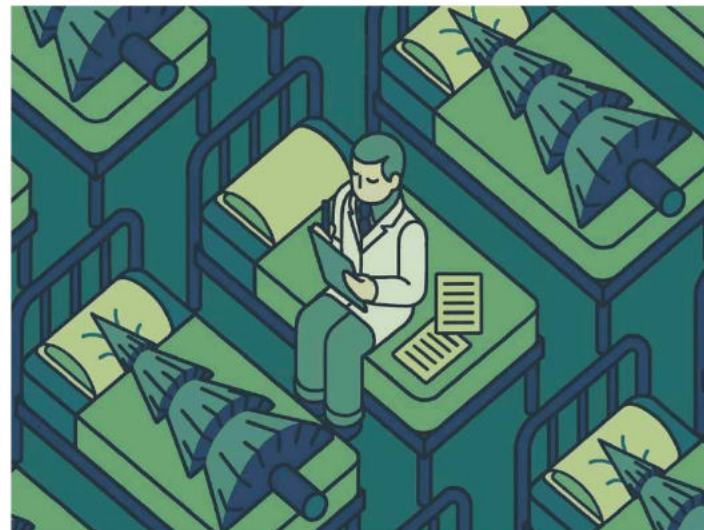


@crawfordcharm shared our excitement for drone-hunting eagles in the Summer issue: "France is naming golden eagles after Musketeers and training them to take down drones. Let us be more like France"

Researcher @azlinksky let us know our illustration for his tree-sleep research was on the money: "Thanks @RajalLockey for the pic, that is exactly what we did! Proud to be @sciencefocus listed #LIDAR #sleepingtrees"

Referencing our online interview (sciencefocus.com) with the Angry Chef @dalohardly said: "It's so good to see a chef being a success at something other than shouting at minions or odd food combos. It's the real deal"

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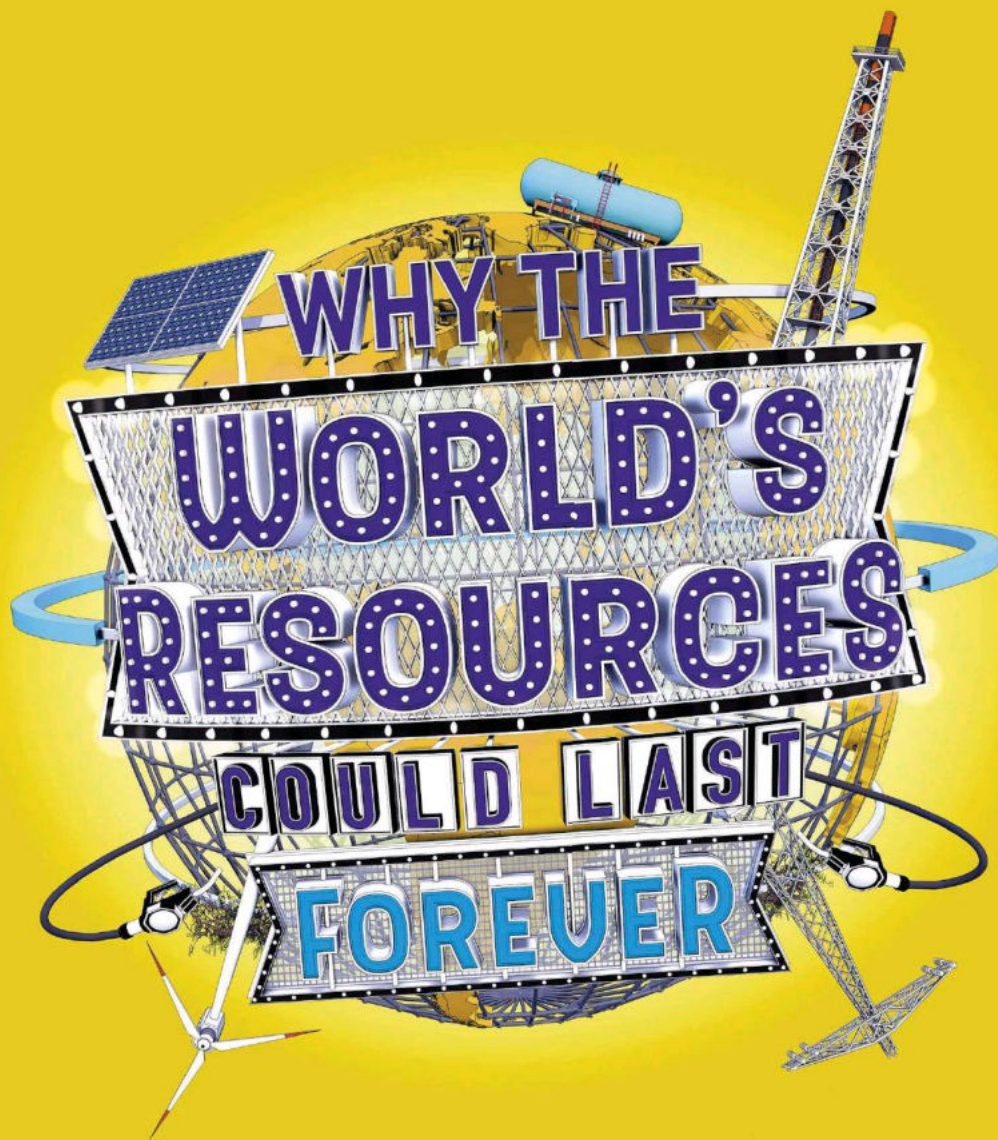


ILLUSTRATION: STEPHAN WALTER/DEBUT ART

THE NEWS IS NEVER SHORT OF HEADLINES TELLING US THAT **ANOTHER RESOURCE IS ABOUT TO RUN OUT.** BUT ECONOMIST AND CONSERVATIVE PEER **MATT RIDLEY** ARGUES THAT HISTORY SUGGESTS **OUR FUTURE MIGHT BE BRIGHTER THAN YOU THINK...**

Steller's sea cow was a most unusual beast. The herbivorous, cold-water-dwelling relative of dugongs and manatees was discovered in 1741 by Georg Steller when he and his shipmates were marooned on the uninhabited Bering Island in the North Pacific.

Rich in blubber and meat, slow-moving and unafraid, this 10-ton, kelp-eating creature proved a tempting target to hunters that winter and in the years that followed. Within three decades of its discovery it was extinct.

This is a tempting metaphor for the impact of human beings on the planet. The seven billion

people on Earth, together with their domestic animals, use a large proportion of the planet's resources. They have already caused the extinction of many species. According to Prof Helmut Haberl of Austria's Klagenfurt University, about 14 per cent of all the new green vegetation on the planet is eaten by us and our tame animals each year, while another 9 per cent is destroyed or prevented from growing at all. It's hard to find an ecosystem we have not affected.

For several decades it has been a staple of the environmental movement that this cannot last, that resources will be exhausted, causing the collapse of civilisation. The first worry was that land would run out, this being the central concern of the Rev Thomas Robert Malthus in his famous 1798 book *An Essay On The Principle* ●

"HERE WE ARE IN THE 2010s WITH VAST PROVEN RESERVES OF OIL"

◆ *Of Population.* For the next century land was indeed scarce. Humanity only expanded by putting the plough and the cow on to the prairies, the steppes, the pampas and the outback.

Yet the area of land needed to support an individual human shrank dramatically in the 20th Century, as tractors replaced horses; coal and oil replaced wood fuel and hay; and synthetic nitrogen fertiliser (fixed from the air) replaced manure grown on other land. Since 1960, the acreage of land needed to produce a given quantity of food has gone down by 68 per cent. Prof Jesse Ausubel of Rockefeller University calculates that, even with conservative assumptions for population, technology and economic development, humanity will be able to release at least 146 million hectares from farming over the next 50 years – an area more than seven times the size of Great Britain.

Such land sparing is already happening in many rich countries: New England is now mostly forest, whereas it was once mostly farmland. Meanwhile, the United Nations Food and Agriculture Organization said in 2015 that net deforestation has just about ceased: "The net annual rate of forest loss has slowed from 0.18 per cent in the early 1990s to 0.08 per cent during the period 2010-2015".

BURNING ISSUE

In the late 20th Century, fossil fuels were thought to be in danger of running out. As long ago as 1865, the economist William Stanley Jevons predicted that the coal on which British industry depended would soon run short. In his pamphlet *The Coal Question: An Inquiry Concerning The Progress Of The Nation And The Probable Exhaustion Of Our Coal Mines* (1865), he wrote that "It is thence simply inferred that we cannot long continue our present rate of progress". He went on to say that British people "must either leave the country in a vast body or remain here to create painful pressure and poverty".

This led to the 'coal panic' of 1866. With the encouragement of political economist John Stuart

Slow-moving and gentle, Steller's sea cows were an easy target for human hunters



Mill, politician William Gladstone (who later became prime minister) promised to start paying down the national debt while coal lasted, citing Jevons's "grave and urgent facts". Something had gone badly awry in Jevons's assumptions, however. Today, the world is consuming over 30 times more coal each year than it did then, yet the amount of remaining coal is sufficient to last thousands of years at current rates of use. Under the North Sea alone, there are billions of tonnes of it. We are likely to stop using coal long before we run out of it.

Oil was the next resource thought to be in imminent danger of exhaustion. In 1914, the United States Bureau of Mines predicted that American oil reserves would last for 10 years. In 1939 the Department of the Interior said American oil would last 13 years. President Jimmy Carter announced in the 1970s that: "We could use up all of the proven reserves of oil in the entire world by the end of the next decade". Yet here we are in the 2010s with vast proven reserves of oil and even more unproven ones, thanks to new technologies for extracting it.

Gas was long thought to be the scarcest of the fossil fuels, but not any more. In 1962, M King Hubbert, a widely admired expert on fossil fuel reserves, predicted that gas production in the continental United States would peak before 1980 and by 2020 would have fallen to minimal levels. In fact, today, natural gas production is at record levels, thanks to shale gas.

SHORT SUPPLY?

The track record for other minerals is no better. In 1970 *Scientific American* published an article by a distinguished nuclear chemist, Harrison Brown, who argued that we would have run out of

supplies of lead, zinc, tin, gold and silver by 1990. Two years later a similar prediction, verified by a computer model called World3, appeared in a best-selling book titled *The Limits To Growth*. The book argued that increasing use could exhaust known world supplies of zinc, gold, tin, copper, oil and natural gas by 1992 and would cause a collapse of civilisation and population in the subsequent century.

But a quarter of a century after that deadline, the world is extracting roughly twice as much zinc, copper and gas as it did in 1992, and almost 1.5 times as much gold and oil. *The Limits To Growth* was very influential, however. School textbooks were soon echoing its predictions: "Some scientists estimate that the world's known supplies of oil, tin, copper, and aluminium will be used up within your lifetime," said one.

In 1990 the economist Julian Simon won \$576.07 from the prominent environmentalist Paul Ehrlich in settlement of a bet. Simon had bet Ehrlich that the prices of five metals (chosen by Ehrlich) would fall during the 1980s. Ehrlich had accepted "Simon's astonishing offer before other greedy people jump in" though later claimed he

was "goaded" into taking the bet, while ungenerously growling about Simon: "The one thing we'll never run out of is imbeciles".

Yet the failure of these doom-mongering forecasts has not deterred others from making the same mistake. In 2007 *New Scientist* predicted that the world would run short of indium and hafnium by 2017. It has not happened, and the price of those metals shows no sign of impending scarcity. When I read a story about a mineral running out, I look up its price history. If it's not getting rapidly dearer, then those in the know clearly don't think it is running out. The indium price has halved since 2007, while other rare earth elements have fallen even further.

The mistake was to assume that because the reserves of these metals were small, they would not last. But hafnium is produced as a by-product of zirconium mining – so there are no reserves. Tim Worstall, a rare-earth dealer, could not conceal his disgust: "The idea that we're going to run out of hafnium, gallium, terbium, or another oft-mentioned, germanium, could only be advanced by people wallowing in their own purblind ignorance. There's not the slightest ◆



ABOVE LEFT: Until the late 1960s, coal was the UK's main energy source

ABOVE: Oil pumps at sunset in California

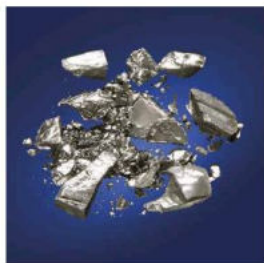
PHOTOS: GETTY IMAGES



ABOVE: Oil sand being mined in Canada. Oil sand is a deposit consisting of a mixture of clay, water, soil and bitumen. Once the oil has been extracted and separated, it can be refined to create fuels – it is less efficient to extract than conventional oil

RIGHT: Germanium, a rare earth element, is obtained during the smelting of zinc ores. It is used for the manufacture of optics

MAIN IMAGE: A mound of potash fertiliser stored at a potash mine in Unterbreizbach, Germany



“possibility of us even running a bit short of any of them for thousands of years.”

Still the predictions of elements running out kept coming. In 2012, Jeremy Grantham, a financier who funds climate change pressure groups, published an editorial in *Nature*. “Then there is the impending shortage of two fertilisers: phosphorus (phosphate) and potassium (potash),” he wrote. “These two elements cannot be made, cannot be substituted, are necessary to grow all life forms, and are mined and depleted. It’s a scary set of statements... What happens when these fertilisers run out is a question I can’t get satisfactorily answered and, believe me, I have tried.”

He cannot have tried very hard. These two elements are never used up, they are just transferred from mines to farms. The highest-grade ores may run out, but there are vast quantities of lower-grade ones down to and including the stuff that has already been used and has ended up back in the sea or the soil. Grantham’s mistake was to confuse reserves with resources. It takes money to turn a resource into a

reserve, so companies that mine phosphorus and potassium don’t prove more reserves than they need for the foreseeable future.

RENEWABLE RESOURCE

This example reminds us that the distinction between renewable and non-renewable resources is confused. A phosphorus atom is renewable – you can use it over and over again. It’s possible that one or two of the trillions of phosphorus atoms in your DNA were in Leonardo da Vinci at some point. Imagine: Leonardo defecated; the sewage ended up in the Mediterranean where it fuelled phytoplankton that got eaten by a fish, which migrated south through the Atlantic and got eaten by a bird which landed on an island off Africa and defecated, leaving guano on the rock that was mined in the 19th-Century to make fertiliser that was spread on an English field, where it got recycled through many generations of plants before ending up in you, via a burger.

Whales or woodlands, by contrast, though renewable, are indeed capable of running out. After killing hundreds of thousands of whales in the 19th Century, we came close to having none left, then along came crude oil just in the nick of time to save them (kerosene lamps displaced whale oil). After damming the streams and felling the woods of Britain for energy throughout the Middle Ages, we were running dangerously short of energy sources. Then along came coal and we began replanting our forests and freeing our rivers.

It’s a bizarre but true fact that organic, renewable resources run out all too easily – mammoths, passenger pigeons, white-pine forests, Steller’s sea cows – while no inorganic resource has even come close to running out: not oil, gas or coal; not silver, copper or phosphorus; not limestone, granite or sand. As somebody once said, the Stone Age did not end for lack of stone.

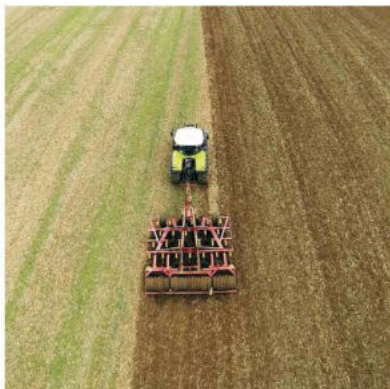
STRUGGLING PLANET?

To sustain our current lifestyle, we humans require 1.4 planets’ worth of resources. That’s ☉

PHOTOS: GETTY IMAGES, SCIENCE PHOTO LIBRARY



“WHALES OR WOODLANDS ARE INDEED
CAPABLE OF RUNNING OUT”



LEFT: More productive farms could lead to less land being taken from nature

● the number calculated by the Global Footprint Network, which defines the ecological footprint as “A measure of how much biologically productive land and water an individual, population or activity requires to produce all the resources it consumes and to absorb the waste it generates using prevailing technology and resource management practices.” In short, we are consuming the Earth’s store of food, fuel and fibre 1.4 times as fast as it can be replenished. But upon examination this number is misleading, almost to the point of dishonesty. More than half of it consists of the land that would be needed by each person to plant trees with which to absorb their own carbon emissions. If you take the view that we can cut emissions, or find better ways to sequester them, or even cope with at least some increase in them, then the footprint shrinks and we are living well within our ecological means.

Environmentalists use a formula called IPAT: impact = population x affluence x technology. The more people there are, and the richer they are and the more technology they have, the more damage they do to the environment. But this cannot be right. Human impact has been decreasing in rich countries as a result of new technology.

For example, by switching from organic to inorganic resources (diesel instead of hay; concrete and glass instead of wood; plastic instead of leather), we reduce our footprint – that is to say, the amount of land the average person needs to support their lifestyle. By using new technology we shrink our requirement for land and water. Let’s compare a person who has plastic seats in their car, say, with someone who has leather seats. The plastic footprint is the area occupied by the oil well, the refinery, the plastic factory, the car factory and so on, divided by the number of

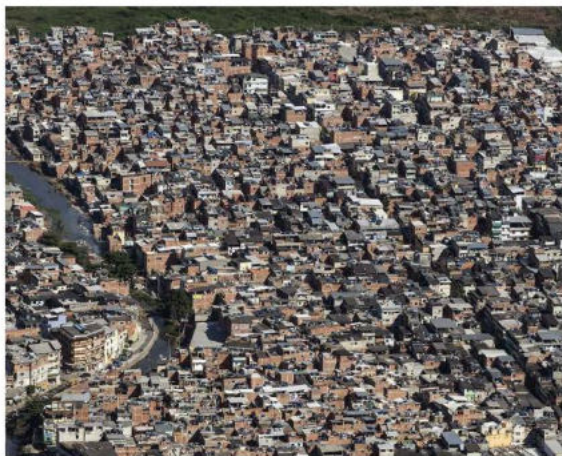
customers they supply. The leather footprint is the farm on which the cow lived, plus the various abattoirs and factories that processed the leather, again divided by the number of people who were supplied. Broadly speaking, the farm dwarfs the other footprints because it takes several acres of grazing per cow and therefore per customer. In the case of fuel, the energy density of an oil well, in Watts per square metre, is thousands of times higher than that of a woodland.

It is no accident that wolves are increasing, lions decreasing and tigers holding their own: wolves live in rich countries, lions live in poor countries and tigers live in middle-income countries.

The opposite theory to IPAT is ‘sustainable intensification’, also known as eco-modernism: the idea that the more productive we make our farms, mines and factories, the less we need to purloin from wild nature. Thanks to irrigation and fertiliser, including the effect of extra carbon dioxide on global greening, humankind increases the productivity of many parts of the planet, even as we pinch a big chunk of that productivity for our own needs. It is therefore possible to imagine that a century or two hence we could have nine or ten billion prosperous people on Earth, but just as much forest and wildlife as if we were not here at all. We might even have brought extinct species back. If we can read the genome of Steller’s sea cow from its bones, then we might be able to revive it. ●

Matt Ridley is a Conservative peer in the House of Lords. He is also a columnist for *The Times*, economist and author. His family leases land for coal mining in Northumberland.

BELOW: Our population is increasing, but that doesn’t have to be bad news for the planet



AN ALTERNATIVE VIEW

Richard Heinberg is a senior fellow at the Post Carbon Institute. He argues that right now we have an opportunity to alter our planet’s future for the better, but we could miss it if we don’t act quickly enough

Anti-environmentalists often use a three-part strategy to talk their way around resource limits. First, sow doubt by cherry-picking a few instances where predictions of scarcity didn’t pan out. Second, use the shaky foundation of these failed predictions to dismiss scientific evidence about resource limits. Third, advance the seductive idea that we don’t have to change our behaviour because machines and markets will solve all environmental problems.

That last point sounds too good to be true, because it is. While we’ll technically never run out of non-renewable resources, there are real impacts from depletion. The harvesting of Earth’s non-renewables follows the low-hanging fruit principle. Extraction industries target resources that are easy to get. As these are exhausted, miners go deeper and move to lower-quality resources that are often more abundant. But these entail higher energy and monetary costs, and worse environmental impacts. We’ll reel from those costs and impacts long before we’re down to the last molecule of any resource.

The oil industry offers an apt example. Decades ago, drillers focused on petroleum deposits located onshore at moderate depth, that were cheap to tap. With few exceptions, geologists no longer find such deposits. The industry focuses instead on deepwater oil, arctic oil, bitumen, and ‘tight oil’ that’s produced by fracking.

“WE EXTRACT AND CONSUME RESOURCES AT FAR HIGHER RATES THAN ANY PREVIOUS CIVILISATION”

These resources are more expensive to extract and bring worse ecological impacts, including spills in the environment and the consumption of other resources (for example, water and sand for fracking). Plus it takes more energy to produce this oil, so it yields less net energy for society. Meanwhile, the oil industry’s profits are declining and its debts are soaring. From the industry’s perspective, the solution would be higher prices, but high oil prices

depress the overall economy, reducing demand. There is no longer an oil price that works for producers and consumers.

Why not recycle all non-renewable resources? We should certainly try, but recycling is no panacea. Sometimes recycling is too hazardous, such as when products contain toxic chemicals. Sometimes there’s little that can be made from a synthetic material after first use, as with many low-grade plastics. Recycling often has prohibitive energy or monetary costs. Some materials (including phosphorus in fertilisers) become so dispersed that collecting and recycling them would be impractical.

Depletion of non-renewables contributed to the collapse of past societies. Today, we extract and consume resources at far higher rates than any previous civilisation. This is possible due to cheap energy from fossil fuels, which enables us to mine, transform and transport other resources in ever-greater quantities, even as resource quality declines. But fossil fuels are depleting too. Some say it won’t be easy to run industrial societies without extracting ever more non-renewable resources. Yet we have no choice. Depletion will bite harder every year until we make recycling non-renewables easier, use fewer toxics, and transition to renewable resources for most purposes, especially for energy. Once the transition is accomplished, we’ll no longer be vulnerable to the economic and environmental consequences of non-renewable resource depletion, such as climate change and pollution. Wind and solar power is often cheaper than electricity from fossil fuels, and the public overwhelmingly favours renewables and recycling.

Opportunity waits, but not forever. ●

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GUNSHOT
TRIANGULATION
IN PROGRESS...

FIGHTING CRIME

DRONES SENT
TO INVESTIGATE

Criminal masterminds had better watch out. Scientists are on their tail and have some clever new ways to catch them. In this special report, we look at the advances that are revolutionising criminology and forensics

WORDS: ANDY RIDGWAY

PREDICTIVE POLICING

CAN WE PREDICT CRIMES BEFORE THEY HAPPEN?

It's 4:30am on a Friday morning in August and there's a heavy police presence in a quiet London suburb. It's a respectable, leafy area and right now, nothing is happening. In fact, it's been quiet for the past few days. But the officers are on high alert. They've been sent at the say-so of a computer that's calculated, on the basis of the data fed into it, that a wave of break-ins is highly likely within the next 24 hours. In other words, they're policing crimes that they *think* will happen, rather than ones that *have* happened. This is predictive policing. And it's about to get much, much more sophisticated.

The idea of predicting where crimes will take place isn't new. For decades now, police forces in the UK and US have been creating 'hotspot' maps that identify the areas where most incidents are taking place, and then sending more police officers to those areas. Predictive policing takes this to the next level, crunching big data using algorithms based

on those that help to predict when and where the next earthquake aftershock will be, or how a disease will spread.

These algorithms generate information that police officers can act on, and it seems to work. In tests, their predictive powers appear to outperform the more traditional techniques used by crime analysts. Their successes have led to predictive policing being adopted by several US police departments, such as California and Arizona, as well as Kent Police in the UK.

But not everyone's convinced about predictive policing – or how it's implemented at least. Among them is criminologist Prof John Eck at the University of Cincinnati. His problem isn't so much with the predictive policing software itself, but the idea of sending out large numbers of staff to patrol problems highlighted by the algorithms. "Why would you want to keep sending large amounts of expensive public servants to

these locations?" he says. "Instead, we should be asking why this location has a persistent crime problem, and what we can do to keep it from happening." Eck would prefer it if the police encouraged owners of businesses and other properties highlighted as crime hotspots to step in and make changes, such as shops with high shoplifting rates repositioning displays. Critics have raised other concerns too, such as the possibility of crimes simply shifting to other locations when problem areas are targeted by the police.

But predictive policing is becoming more and more widespread, and it could be about to change radically. Earlier this year, a bunch of mathematicians led by Prof Mark Girolami at Imperial College London were awarded £3m from the government to take predictive policing to the next level. Whereas today's tools just rely on crime data – such as the locations, dates and times of incidents – Girolami and his team will be working on how to integrate the likes of Twitter feeds, newspaper reports and socioeconomic data to sharpen the predictions. Text documents will be converted, or 'coded', into numerical representations, with counts of words and phrases – such as descriptions of assaults or break-ins – to highlight geographical areas of concern. "All of these streams of information will be coded and integrated using our 'secret sauce'," says Girolami, referring to the complex maths that will draw all of this disparate data together.

What's more, this new predictive tool aims to work out the extent to which crime will be displaced to a neighbouring area when the number of police in the original area suddenly shoots up. "Our models will be able to propagate what would happen," says Girolami.

Staff from the University of California demonstrate predictive policing with Los Angeles police



HEAD CAM 05126
OFFICER BODIE DOYLE
HOLD AR: ACTIVATED

NEURAL HACKING TERMINAL
STATUS: ILLEGAL
HEALTH RISK: NONE

USED NEURAL IMPLANTS
STATUS: ILLEGAL
HEALTH RISK: SEVERE

ESCAPE ROUTE

"SCENES GET OVERLAID WITH INFORMATION FROM A CSI EXPERT SO EARLY ARRIVERS KNOW WHAT TO BAG UP AS EVIDENCE"

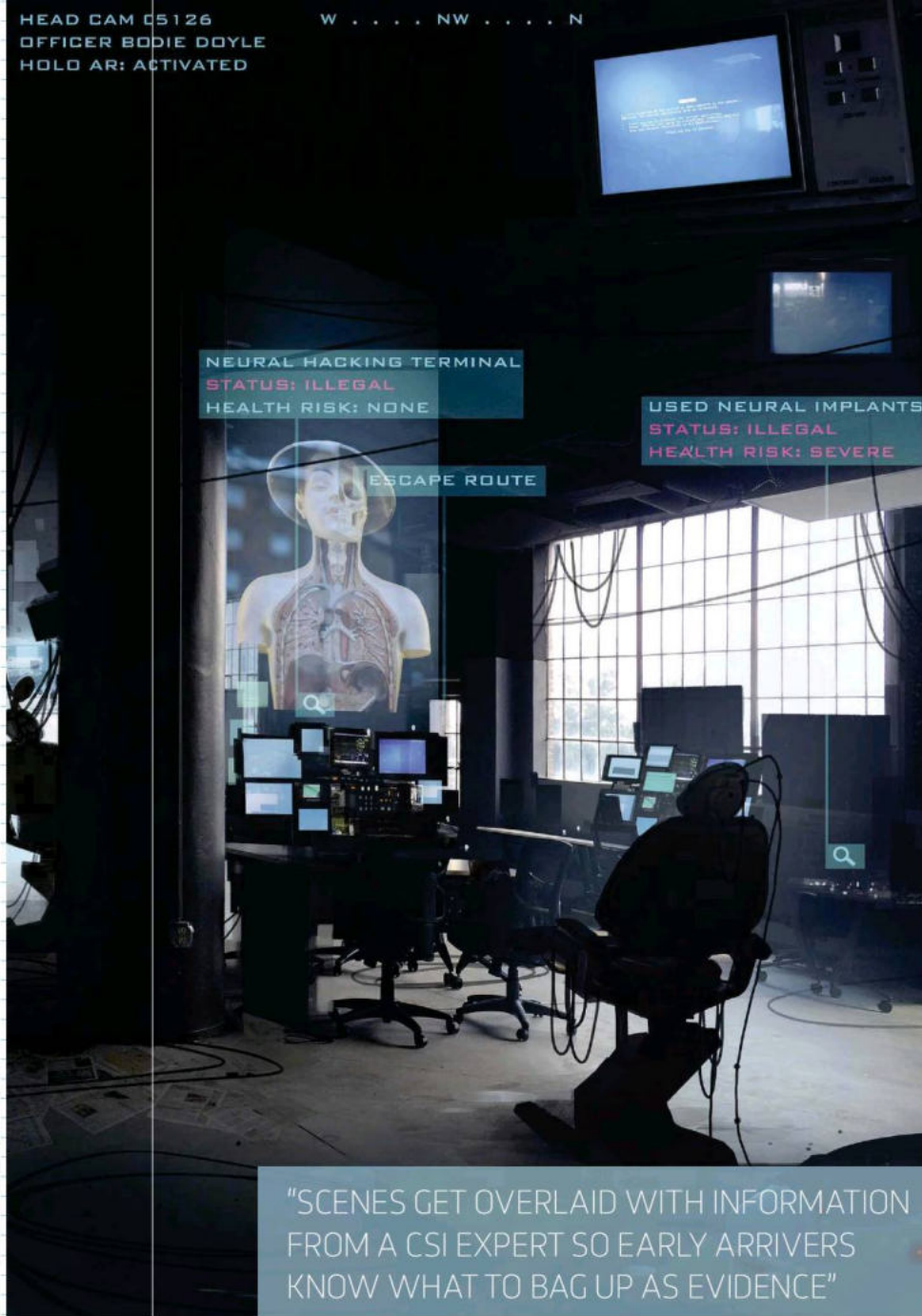
AUGMENTED CRIME SCENES

Being the first police officer to arrive at a crime scene is a stressful business. Are the culprits still here? Is it safe for me to walk around? Does anyone need medical help? In these circumstances, it's easy for what might later turn out to be a vital piece of evidence to be 'polluted' in some way – trodden on, knocked over, or mishandled. But soon, officers arriving at such scenes may have the finest minds in crime scene investigation to guide their every move, even if they're working at the other end of the city.

The idea is to use augmented reality, where a view of the real world is 'augmented' in some way with digital data. Researchers at Delft University of Technology in the Netherlands have been working with Dutch police, the Netherlands Forensic Institute and the Dutch Fire Brigade to develop a system in which crime scenes get overlaid with information from a CSI expert so early arrivers know what to bag up as evidence or investigate further.

In one recent trial of the technology, officers were faced with a mock ecstasy lab in the kitchen of an apartment. A smartphone mounted on an officer's shoulder beamed live video to a crime scene investigator who then annotated what they could see, highlighting the chemicals and equipment that would need to be removed for analysis. The officers on the ground viewed the scene and annotations through a second smartphone they were holding, and, in another test, the smartphones were replaced with augmented reality headsets.

PHOTO: SHUTTERSTOCK ILLUSTRATION VLADKO KRIZAN



EXTRAORDINARY EVIDENCE

Even the tiniest scraps of evidence can help to catch a criminal

GUNSHOT FORENSICS

Gunshots ring around a city centre street. One man lies dead in the road and another tells the police he fired his gun in self defence after being shot at. No one saw what happened. The one thing the police do have is video footage from a mobile phone, while it doesn't actually show the shooting, the sounds of the gunshots have been captured. Dr Robert Maher at Montana State University is the man to call. By firing assorted weaponry near a semicircle of 12 microphones, he has developed a database of soundwaves produced by different guns. The aim is to enable different gun types to be distinguished from a sound recording, helping police unpick exactly what went on in cases like our shoot-out.



GENETIC MUGSHOTS

Soon, a drop of blood could provide forensic scientists with all the information they need to draw the mugshot of a suspect. Researchers are starting to establish how our genes shape our faces, and if they manage to hone their techniques enough, it would mean that they could recreate a person's visage from a tiny DNA sample. Dr Mark Shriver, an anthropologist at Pennsylvania State University, is on the case. Working with Dr Peter Claes, an imaging specialist in Belgium who captured three-dimensional images of over 600 volunteers' faces, he analysed a bunch of genes and was able to pinpoint 24 versions, or 'variants', of 20 genes that would help with predicting someone's facial shape.



SCENT OF A VILLAIN

In the future, could vanishingly small traces of perfume or aftershave on a shirt could be enough to bring an attacker to justice? Fragrances are notoriously difficult to detect because they are made up of volatile molecules that evaporate rapidly. But a team led by PhD student Simona Ghergel at University College London has found that the cocktail of compounds that make up perfumes can be transferred between clothes and subsequently detected. The highly-sensitive detection technique is known as 'gas chromatography-mass spectrometry'. In one test, when two fabrics had been in contact for just one minute, 15 out of 44 fragrance components in a male cologne were found.



PHOTOS GETTY IMAGES ILLUSTRATIONS VLADIMIR ZAN

WHAT'S IN A HAIR?

Give a strand of your hair to Dr Glen Jackson at West Virginia University and he can tell your age, sex, what you eat and how much you exercise. For police with little to go on from a crime scene other than a few bits of hair, this information can be gold dust. Jackson and his team measure the ratio of isotopes – atoms of the same element with different numbers of neutrons – within the 21 amino acids found in keratin, the main component of hair. So far, they have found 15 isotope ratios that provide a window into who someone is.



E. COLI
GENOME IDENTIFIED
SUSPECT ORWIN ALBANI

ARMED ROBBERY
AGGRAVATED ASSAULT

VIEW FULL PROFILE: Y/N

MICROBIAL FINGER-PRINTING

It's a slightly unsettling thought that each of us sheds around 30 million bacterial cells from our bodies every hour. They waft into the air and cling to objects we've touched, like furniture and mobile phones. The community of microbes that live on and in our bodies, our microbiome, is also unique. Soon, criminals may be linked to a crime scene by the trail of bacteria they haplessly leave behind. In one study, Dr James Meadow, then at the University of Oregon, found that people could be identified simply from the invisible cloud of bacteria they left in the air – even when the air was sampled four hours after they had left the room.

POLICE LINE POLICE LINE POLICE LINE

LIAR, LIAR, BRAIN'S ON FIRE

Can brain scans reveal when someone is fibbing?

Since 2000, neuroscientists have been investigating whether fMRI (functional magnetic resonance imaging) brain scanners could make the ultimate lie detectors. fMRI works by measuring blood flow of blood in the brain – the harder a specific region is working, the greater the blood flow to it. Research on fMRI and lie detection involves popping a bunch of volunteers into a scanner and inviting them to tell porky pies. In some instances, researchers have found the tests to be 100 per cent accurate, with brain regions such as the ventrolateral and medial prefrontal cortices springing into life and giving away the deception. And in one study, published in the *Journal Of Clinical Psychiatry* in 2016, fMRI was 24 per cent more likely to spot fibs than a traditional polygraph test.

But many neuroscientists are sceptical of fMRI's ability to detect lies. For one thing, the test seems easy to beat. In a piece of research, Harvard students were asked to lie while they were in an fMRI machine. The accuracy of the tests slumped to 33 per cent when the lying students wiggled their fingers and toes.

Designing a test that's realistic is tricky, too – something that worries Dr Anthony Wagner, a

psychologist at Stanford University. "Is an instructed lie in a low stakes situation about a meaningless event the same as a person choosing to lie about something they observed or an act they committed which, if caught, could see them paying a significant fine or going to jail?" he says.

Such concerns haven't stopped US lawyers trying to get fMRI evidence admitted in court to prove that their client is telling the truth. Judges have refused the requests – so far. "Sooner or later, there will be a judge who will decide to go against the mainstream and allow this," says Dr Daniel Langleben at the University of Pennsylvania. "It will be a precedent and there will be another case, and another one, then there will be a free-for-all. It's not a good outcome."

Langleben argues that it would be better to conduct a large trial of fMRI lie detection to shine a light on issues such as how sensitive the technique is to attempted trickery, such as a criminal wiggling their fingers and toes.

"MANY NEUROSCIENTISTS ARE SCEPTICAL OF FMRI'S ABILITY TO DETECT LIES. FOR ONE THING, THE TEST SEEMS EASY TO BEAT"

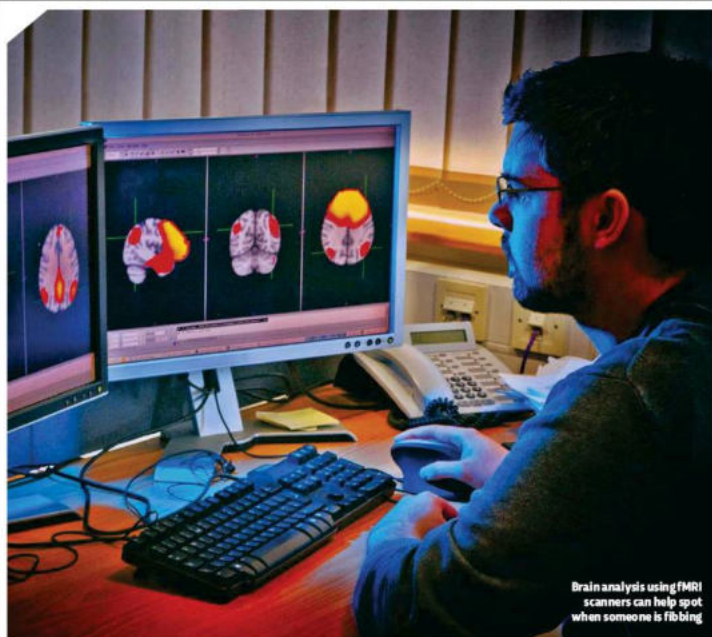


PHOTO: SCIENCE PHOTO LIBRARY X2 ILLUSTRATION: VLAD KIRZAN



AI DETECTIVES

There has been a spate of armed robberies in the city. And detective VALCRI has been tasked with scanning thousands of records of previous crimes to find patterns and connections that could help track down who is responsible. The thing is, VALCRI isn't human.

VALCRI, or Visual Analytics for Sense-making in Criminal Intelligence Analysis, is an AI system that can scan police crime reports, interviews, videos and pictures, interpreting words and recognising faces. Its aim is to identify links between crimes that might provide detectives with an all-important breakthrough. These links may be similarities in the *modus operandi* of the thief, a reoccurring weapon, or similar descriptions by witnesses. Funded by the EU and led by Prof William Wong at Middlesex University London, VALCRI can learn, too. When a crime analyst decides whether a piece of evidence identified by the system is relevant or not, it will use that information to improve future searches. It is currently being tested by police in the West Midlands and in Antwerp, Belgium.

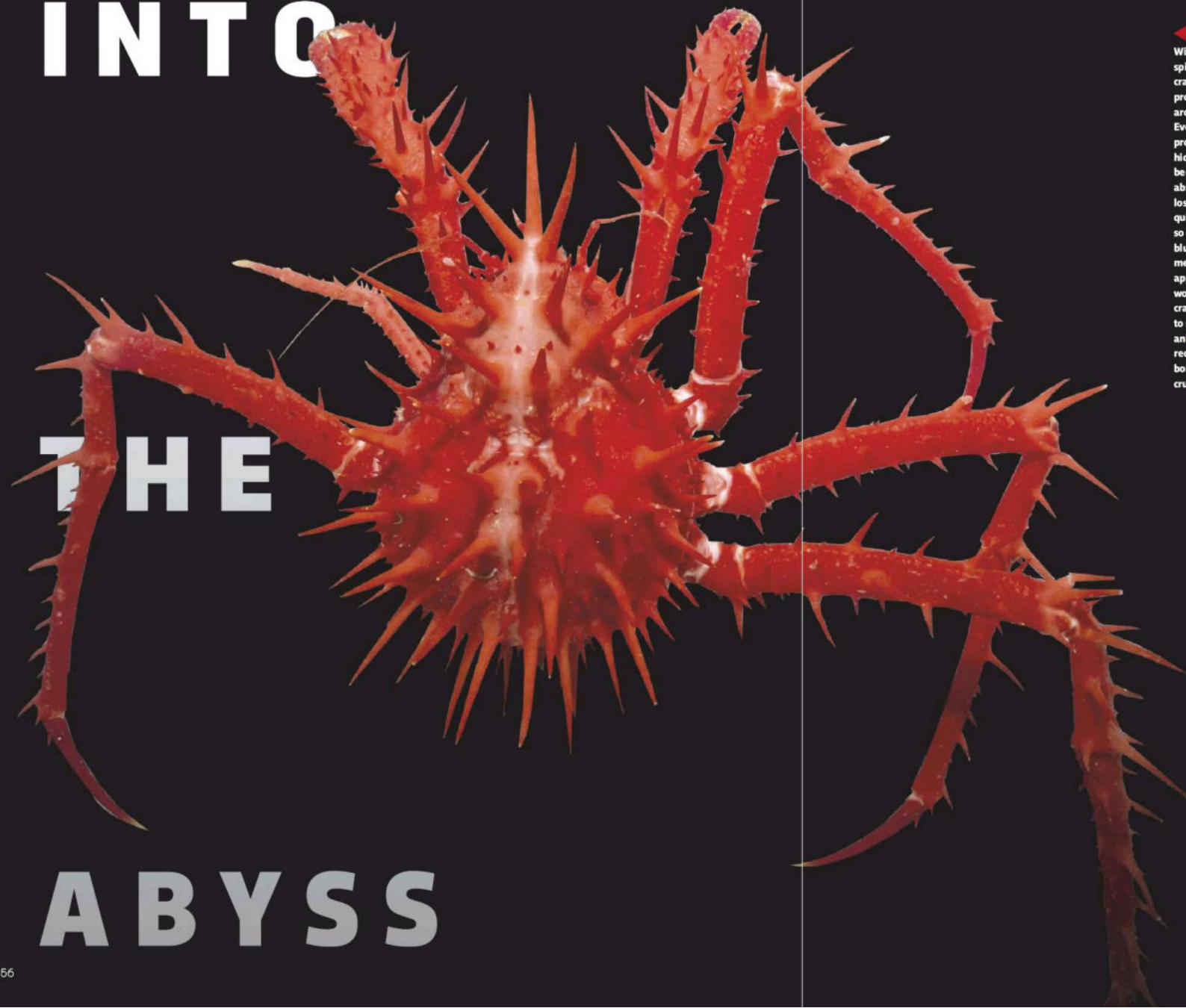
VALCRI isn't alone – other AI systems for crime detection have been developed to do everything from sifting large volumes of documents for clues in fraud cases to helping forensic teams determine how many people have contributed to a large, multi-person DNA sample – something that's tricky to fathom at present. 

Andy Ridgway is a Bristol-based freelance science writer. He tweets from @AndyRidgway1

INTO

THE

ABYSS



◀ SPINY CRAB

With its spectacularly spiky body armour, this crab was immensely well protected as it stalked around on the seabed. Even its colour is protective, helping it hide in the dark depths because seawater absorbs red light. "You lose it [red light] pretty quickly as you go down, so everything becomes blue," says Bray. This means that red pigments appear black, which would have made the crab incredibly difficult to spot. Most deep-sea animals haven't evolved red vision – an added bonus for this crustacean.

FOR THE FIRST TIME, SCIENTISTS HAVE EXPLORED THE DEEP SEA OFF AUSTRALIA, REVEALING A WHOLE NEW WORLD THAT'S FILLED WITH BIZARRE CREATURES

WORDS: DR HELEN SCALES

PHOTOS: ROB ZUGARO/ASHER FLATT/CSIRO

Faceless fish, zombie worms and herds of sea pigs were among the wonders hauled up from the ocean depths by a research team working off Australia's east coast. Scientists from seven countries spent a month on the research vessel *RV Investigator*, starting in Tasmania and working their way north as far as the Coral Sea. While the shallower waters in this region are well known, this was the first expedition to focus on the unexplored depths.

Along the way, the team, led by Dr Tim O'Hara from Museums Victoria, mapped the seabed in detail for the first time with underwater cameras and sonar. They discovered rock-covered plains, colossal canyons and mountains. Every 1.5° of latitude they sent a trawl net to the seabed. It took up to six hours for the net to go down to 4,000m (2.5 miles) and come back up. "It makes you appreciate what you get," says Dianne Bray, a fish specialist from Museums Victoria who was on the ship. "These things are so valuable and precious."

A metal sled was dragged along the bottom to gather mud-dwelling creatures and sample the seabed for signs of pollution. As well as cans and bottles, it brought up piles of clinker – residue from coal-powered steamships that used to ply these waters in the 1800s and early 1900s.

Of thousands of animals collected, perhaps a third are new to science, although it will take months of hard work to tease out the details. The preserved specimens will be used for generations, to understand how Earth's biodiversity is changing. "They're for the people who aren't yet born who will ask questions that we can't even envisage, using methods that we can't imagine," says Bray.



▲ **LIZARDFISH**

Two menacing lizardfish were collected on the trip, from a depth of 2,500m (1.6 miles). "It has just nasty, nasty teeth," says Bray. Huge eyes help them detect the faint glow of bioluminescence, which is a form of light made by many marine animals. Lizardfish are hermaphrodites, which means they have both female and male sex organs. This is a great reproductive strategy in the vastness of the deep sea, as the fish don't have to worry about finding a partner of the opposite sex when they want to reproduce – any member of the same species will do.

◀ **GELATINOUS CUSK EEL**

This fish lives in the permanent dark and has tiny eyes that may not work well. Yet somehow, it finds mates in the inky depths and gives birth to live young. The research team found another cusk eel species, which they nicknamed the 'faceless fish'. But it turned out not to be new to science. The species had previously been collected 140 years ago in the northern part of the Coral Sea, on the historic voyage of the British ship HMS Challenger, the world's first round-the-world oceanographic expedition. The new specimen is already on display to the public at Museums Victoria.

COOKIECUTTER SHARK ▶

These fearsome sharks are rarely seen alive, but are mostly known from the circular wounds they leave in their prey (hence their name). They spend their days in the 'twilight zone', 1,000m down, then rise up at night to hunt in shallower waters. The sharks measure about half a metre in length, and latch onto large fish, dolphins and whales, before slicing out a plug of flesh with their razor-sharp teeth. Cookiecutters glow in the dark, which eliminates their shadow in the dim blue light of the twilight zone. A dark band on their skin may fool their victims into thinking they're smaller prey fish, which lures them within striking distance.





▲ BATFISH

This unidentified juvenile batfish is a relative of deep-sea anglerfish. It sits on the seabed and slowly shuffles around using its front fins as legs. "They're not strong swimmers, they have really soft gelatinous flesh," says Bray. "They're kind of cute." The fish also has a 'lure' on its forehead. This is a key character of many anglerfish that are ambush predators; they sit and wait for other animals to wander up and mistake their wagging lure for food.

▼ PEANUT WORM

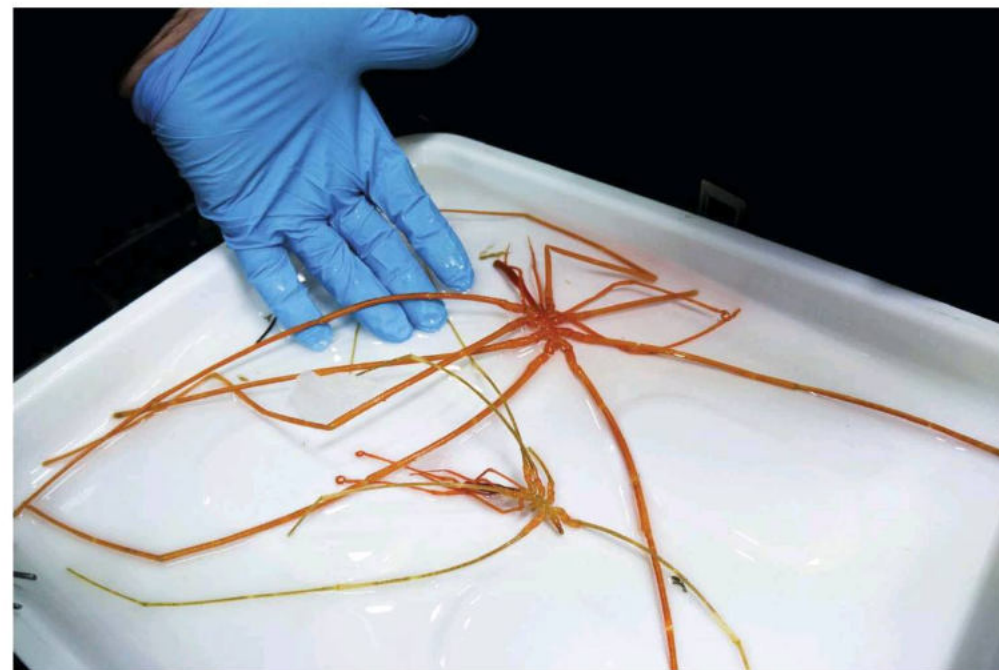
Let's face it – we're all thinking the same thing. But this is not a penis worm (although they do exist: a whole phylum of penis worms lives in mud in shallower seas). This worm belongs to a different group of seabed dwellers, called 'sipuncula'. They can retract the front part of their bodies when they're threatened, making them look more like peanuts. There are male and female peanut worms, which can either reproduce sexually, by releasing sperm and eggs, or asexually, by splitting themselves in half to produce identical clones – handy if they can't find a mate.





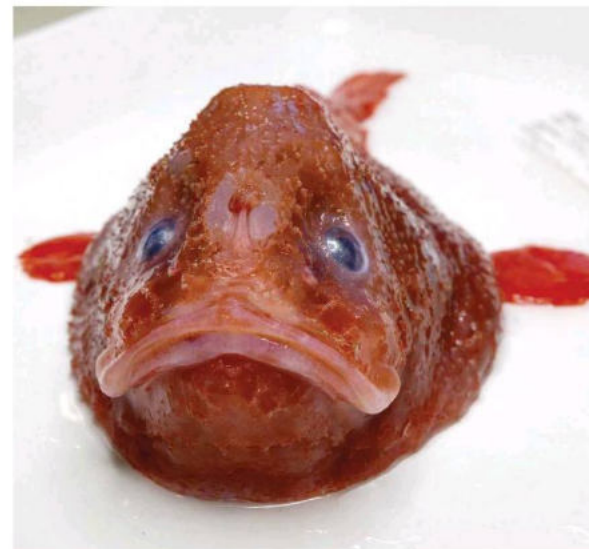
▲ CORALLIMORPH

These invertebrates belong to the same group as anemones and corals. They have tentacles and stinging cells, called nematocysts, for snagging small prey. Unlike more familiar reef-building corals, corallimorphs don't secrete a calcium carbonate skeleton and they don't form colonies. Countless other spineless creatures were brought up in the expedition's sampling nets, and preserved specimens will be sent around the globe for experts to fully identify. But it's still too soon to say how many species are new to science. "In terms of invertebrates, that's a fair way down the track," explains Bray.



▲ SEA SPIDER

If you suffer from arachnophobia – relax. These knobby-kneed creatures aren't actually spiders but a separate class, known as pycnogonids. They've been around for hundreds of millions of years, and simplicity is the key to their success. "They're all legs and no body," says Bray. They have no gills or digestive organs, and use a proboscis to suck the juices from anemones. Tiny sea spiders inhabit rock pools around the UK, but down in the deep, giants can have 60cm leg spans. They walk across the seabed and occasionally drift spread-eagled on the current. Males carry fertilised eggs glued to their bodies.



◀ COFFINFISH

The coffinfish sucks in water when it feels threatened and blows itself up like a balloon. This makes it appear bigger so predators might leave it alone (pufferfish use the same tactic). Similar fish have been found elsewhere in the deep sea, including Indonesia, Japan and Hawaii. But this is a first sighting for Australia. Bray explains that she'll need to X-ray it and possibly sequence its DNA to find out whether it's the same species. "It would be really cool if it's actually new," she says. 🐡

Dr Helen Scales is a marine biologist and author. Her next book, *Eye Of The Shoal*, is out in May 2018.

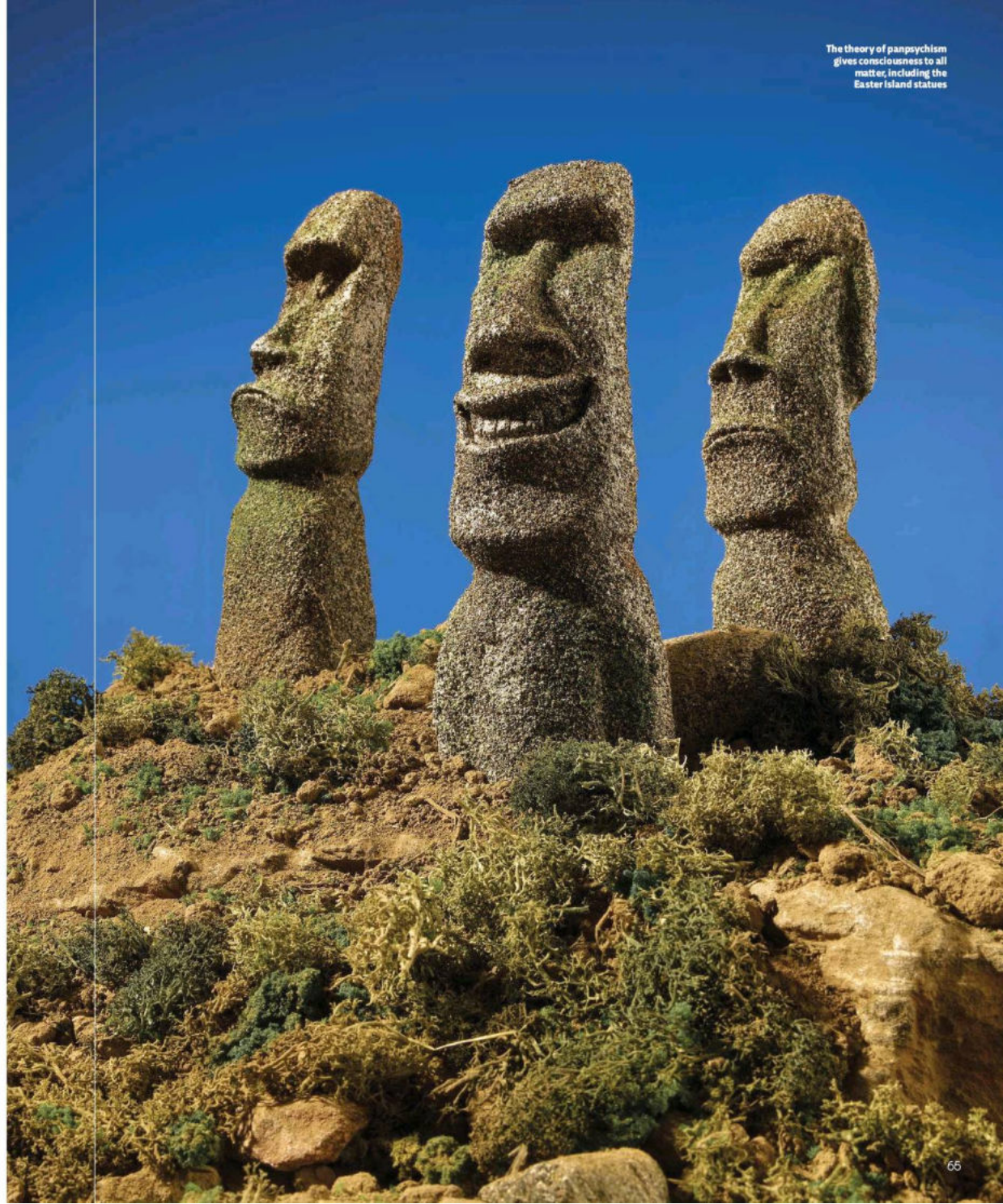
Panpsychism – the idea that all matter, including rocks and particles, is conscious – is growing in popularity. Why? Because this theory may answer one of the biggest questions in science

WHERE DOES CONSCIOUSNESS COME FROM?

WORDS: PROF YUJIN NAGASAWA

Yujin is a professor of philosophy at the University of Birmingham. His new book *Miracles: A Very Short Introduction* will be out in November. He tweets from @yujinnagasawa

PHOTO: GETTY



The theory of panpsychism gives consciousness to all matter, including the Easter Island statues

When I was small I often entertained the idea that the Moon was alive and observing me. On my way home from school, I enjoyed looking up into the sky, believing that the Moon kept following me to ensure that I

arrived safely. This is an example of animism, which is the belief that inanimate objects, such as stones, trees and mountains, are all alive. Jean Piaget, the Swiss pioneer of developmental psychology, collected many examples of child animism, such as bringing home more than one flower at the same time so that they would not feel lonely, and moving stones from paths every now and then so that they would not have to constantly look at the same view. As Piaget observed, animism is commonly present in young children and tends to disappear as they grow up.

A closely related hypothesis to animism is panpsychism. Unlike animism, panpsychism does not necessarily attribute life and full mental activity to inanimate objects, but, like animism, it attributes consciousness to them. According to one version of panpsychism, everything in the Universe – including people, trees, rocks, clouds and even subatomic particles – is conscious because consciousness is a fundamental ingredient of reality.

Many regard panpsychism as an outrageous hypothesis. For example, Karl Popper, an influential 20th-Century Austrian-British philosopher, claimed that panpsychism is “trivial and completely verbal, or grossly misleading”.

However, some scientists and philosophers have recently come to think that panpsychism may offer a solution to one of the greatest mysteries concerning our existence.

BELOW:
Conscious
toys? The idea
may not be as
fictional as it
first appears



CONSCIOUS MYSTERY

In HG Wells's short story *The Country Of The Blind*, a mountaineer called Nuñez arrives at a hidden valley that is cut off from the rest of the world. The valley is occupied by a population consisting entirely of blind people. Nuñez tells them that he has the fifth sense called 'sight' but no one believes him. After living there for some time he falls in love with a local woman. The elders, however, object to their marriage because Nuñez is obsessed with the 'non-existent' fifth sense. His doctor suggests Nuñez's eyes, which are causing his 'delusions', be removed. Is it really impossible, even in principle, for Nuñez to make the people in the country comprehend what it is like to see things?

Wells's story is reminiscent of a philosophical thought experiment introduced in 1982 by the philosopher Frank Jackson at the Australian National University, which vividly illustrates the mystery of consciousness. Imagine Mary, a brilliant future scientist who has always lived in a black-and-white room. Although she has never been outside her room in her entire life, she has learned everything there is to know about reality by studying physics, chemistry and neuroscience from black-and-white textbooks and lectures on a black-and-white television. She knows exactly how the brain works and what kind of neural process takes place in any given situation. Suppose now that Mary leaves her room for the first time in her life and looks at, say, a ripe tomato. It seems reasonable to think that she will say, 'Wow, this is what it is like to see red!' She will learn something new. This seems to suggest that some knowledge can only be captured by conscious experience.

The brain is a highly complex system with the capacity to process information, but it is a mere organ, a material substance. There seems nothing more spiritual or supernatural about it than there is about the stomach or the lung. So how could the brain yield conscious experiences that are so dissimilar to processes like digestion and respiration? How could processes in the brain give rise to vivid sensations and raw feelings, such as the shooting pain of a leg cramp or the sublime pleasure one takes from listening to musical masterpieces? It seems difficult, if not impossible, for science to explain it.

THE PANPSYCHIST SOLUTION

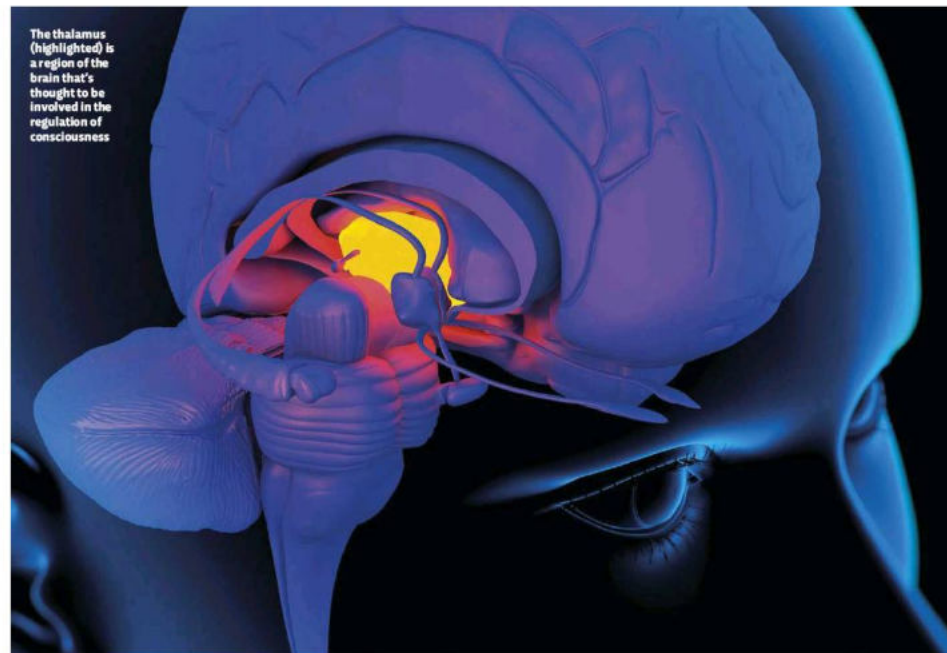
One might claim that the mystery of consciousness arises because we do not know enough about the brain yet. The mystery should be resolved, one might contend, when neuroscience makes sufficient progress. Yet critics find such a projection too optimistic. Physical sciences, such as physics, chemistry and brain science, are adept at explaining natural phenomena in terms of the structure, function and dynamics of material objects and properties. But consciousness does not seem to be a matter of structure, function or dynamics. Why do neural processes have to be accompanied by specific conscious experience? And why does consciousness ●

PHOTOS: GETTY SCIENCE PHOTO LIBRARY

“According to one version of panpsychism, everything in the Universe – including people, trees, rocks, clouds and even subatomic particles – is conscious because consciousness is a fundamental ingredient of reality”



Many children exhibit animism, which is the belief that rocks, trees and inanimate objects have feelings



The thalamus (highlighted) is a region of the brain that's thought to be involved in the regulation of consciousness

● exist in the first place? Physical sciences seem unable to answer these fundamental questions. To use a metaphor, the mystery of consciousness is about explaining the 'magic of turning the water of material processes' into the 'wine of conscious experiences'. Many scientists and philosophers have tried and failed to expose the trick for a long time.

Panpsychists try to solve this mystery by appealing to the radical hypothesis that everything in the Universe, including the subatomic particles of the brain, is conscious. They say that if the constituents of the brain are already conscious, then it is not much of a stretch to suggest that they give rise to a full-scale human consciousness when they are gathered and arranged with the necessary complexity. It is not a surprise that the 'wine of consciousness' is produced from the 'water of material processes' if the water already contains wine.

So what is the consciousness of subatomic particles? Panpsychists do not necessarily say that these particles have conscious experiences in the same way that humans do. Particles have no sensory apparatus such as eyes or ears, so they do not enjoy visual or auditory experiences as we do; they must encounter something much more primitive. That is why some panpsychists call the consciousness of these entities 'protoconsciousness'. Physical sciences postulate many fundamental features of the Universe, such as space-time, mass, charge and spin. These features are fundamental because they cannot be explained in terms of more basic features. Panpsychists say that the consciousness of subatomic particles is comparable to these fundamental features. They are the ultimate building blocks of reality that ground our fully fledged consciousness. Panpsychism offers a simple yet elegant solution to the mystery of consciousness. Consciousness is not a miraculous phenomenon that arises out of nothing in the brain, but something that exists everywhere in the Universe.

Exactly how the consciousness of subatomic particles can combine to form a full-scale human consciousness is a matter of dispute. Some panpsychists hypothesise that smaller conscious experiences merge or fuse to yield full-scale human conscious experiences. Some other panpsychists hypothesise that when an aggregate of small conscious experiences reaches a certain level of complexity, a full-scale human consciousness arises as an emergent property. These hypotheses are inevitably speculative as we do not have direct access to the consciousness of subatomic particles.

Critics argue that panpsychism faces a serious problem of its own: the combination problem. The combination problem was originally introduced by William James, the so-called father of American psychology. James presents the problem with this

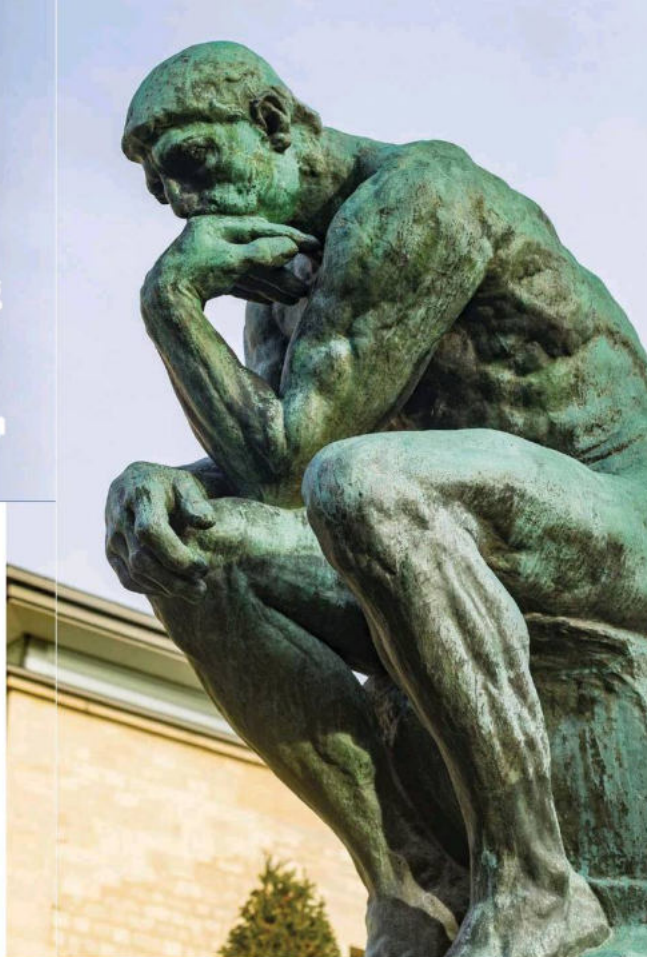
BELOW: Was Karl Popper, an influential 20th-century philosopher, wrong to dismiss panpsychism as nonsense?



ABOVE: Subatomic particles can help us explain the world, but could they also be conscious?

thought experiment. Take a sentence of five words, say, 'It is a beautiful day'. Gather five people and assign one of the words to each person. Stand these people in a row and let each contemplate their own word as intently as possible. Is there now a consciousness of the entire group contemplating the whole sentence? No. Members of the group are individually conscious but their presence does not give rise to a unified consciousness of the entire group contemplating the whole sentence.

"Consciousness is not a miraculous phenomenon that arises out of nothing in the brain, but something that exists everywhere in the Universe"



The point that James tries to make against panpsychism is this: if panpsychism is true, then the subatomic particles that constitute the brain are conscious. However, it seems obvious that by gathering their mini consciousnesses we cannot obtain a full-scale human consciousness. The homogeneity of our conscious experiences seems to contradict the panpsychist thesis that our conscious experiences are aggregates of mini conscious experiences. The combination problem is widely considered the greatest challenge for panpsychism.

THINK BIG

Conscious experiences, which are smooth, continuous and homogeneous, are analogous to smooth paintings rather than to Impressionist paintings consisting of distinct dots of colour. This observation leads us to a variant of panpsychism,

sometimes called 'cosmopsychism'. According to cosmopsychism, the consciousness of the entire Universe, that is, the cosmic consciousness, rather than the consciousness of subatomic particles, is a fundamental feature of reality. This view is remarkably similar to pantheism, which equates the Universe with God. Einstein expressed sympathy with pantheism when he said, "I believe in Spinoza's [pantheistic] God, who reveals himself in the harmony of all that exists."

According to cosmopsychism, our smooth, continuous and homogeneous conscious experiences are segments of smooth, continuous and homogeneous conscious experiences of the whole Universe, rather than aggregates of small conscious experiences of subatomic particles. Smooth, medium-sized paintings (human conscious experiences) cannot be aggregates of distinct small dots (mini conscious experiences) but they can be segments of an equally smooth, large painting (cosmic conscious experiences).

Cosmopsychists say that consciousness is everywhere – not necessarily because subatomic particles are conscious, but because the entire Universe is irreducibly conscious. We may argue about how something large (cosmic conscious experiences) could be more fundamental than something medium (human conscious experiences) but this version of panpsychism does not face the combination problem. Cosmopsychism, however, perhaps stretches the imagination too far.

There is nothing more direct and certain than our own conscious experiences. The 17th-Century philosopher and scientist Rene Descartes famously said, "I think, therefore I am". We can doubt all sorts of things around us but we cannot doubt the reality of our own existence because the very act of thinking or doubting proves the existence of our own consciousness – something must be there to do the thinking or doubting. The mystery of consciousness therefore persists.

So what do I think of panpsychism as a solution to the mystery of consciousness? On the one hand, I think the theory has some gaps to fill. It is unclear what conscious experiences of subatomic particles are, and how aggregates of them can yield full-blown conscious experiences. Without explaining these subatomic experiences fully, panpsychism cannot be considered a successful solution to the mystery. On the other hand, it is a highly attractive theory. It tries to explain how the brain can yield consciousness by stipulating the elegant thesis that the Universe is uniformly conscious. It seems to make more sense than its alternative: that full-blown consciousness suddenly came into existence through evolution in a tiny region of the purely material Universe. ●

PHOTOS: GETTY IMAGES, SCIENCE PHOTO LIBRARY

PROF IRENE TRACEY
EXPLORES THE SCIENCE
OF PAIN IN THE TWO-PART
SERIES FROM AGONY TO
ANALGESIA ON
15 AND 22 AUGUST.

4

PAINFUL FEELINGS

From an evolutionary perspective, pain is old. It is vital because it warns us that there is something present that could cause us serious injury. Pain is subjective, and two individuals will not experience it in the same way.

UNDERSTAND PAIN

Everybody hurts, but why? We explore the science of pain

WORDS: PROF IRENE TRACEY

We may have learnt to tame it with drugs, but pain is one of the certainties of human existence. It can be both physical and emotional, ranging from a searing torment to a mild soreness. But what exactly is it, what function does it serve, and how can we really know how much pain someone is in?

What is pain?

Simple, you'd think. You touch a hot saucepan by mistake and it hurts like hell. You immediately withdraw your hand, rush to the tap and run cold water over it. Phew. No need to rush to A&E. But then it throbs for days, reminding you of the burn and your carelessness until the pain fades away. Lesson learned: you'll be more careful around cookers in future.

This simple incident can tell us a lot about pain. Mostly, it's a brilliant warning system. Without it, you would not have withdrawn your hand, and the injury would be much worse. Pain like this – what we call 'acute pain' – is a good thing: it's key to our survival. That's why the ability to experience pain is shared across species. A few people include plants in this, too, but as plants have no nervous system or brain, it's hard to know how they'd actually *feel* pain when injured or cut. Pain is evolutionarily old, an essential warning that something in the environment can cause us injury, harm, or even death.

Without pain, you're in trouble. We know this, sadly, because there's a rare genetic condition, which we call 'congenital insensitivity to pain' or

CIP, in which a person doesn't get the warning 'hurt' of pain after severely damaging themselves. Historically, they didn't survive to adulthood due to the consequences of unfelt injury.

What does pain do?

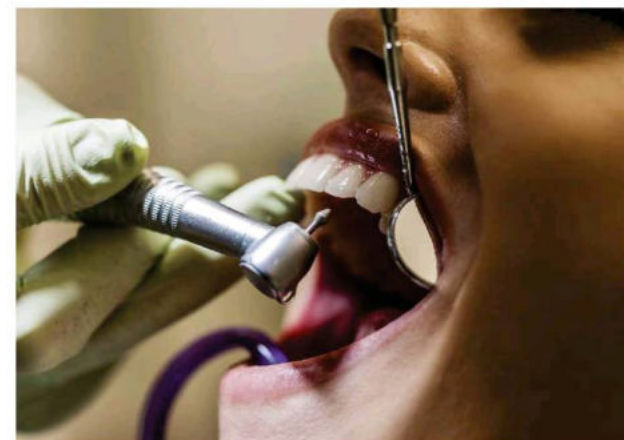
Pain motivates us to act. Think about that hot pan again. Now imagine you'd picked up the pan before realising it was too hot to handle. Your options are to drop it and make a mess, or bear the pain until a solution is found. In an instant, you detect that the pan is hot (thermal), it's on your hand (location), it's painful (intensity), you don't like it (unpleasant), it's engaged your full attention (cognition), and you're not happy about it (emotional). That's a lot

of things, which is why pain is often called a 'multidimensional' experience.

So, what do you do? Well, from past experiences, learnt responses, and potential outcomes (like being told off for dropping the pan) you make a decision and act. Recruiting extraordinary brain-based networks, you are able to block the pain and get the hot pan to safety – then it's back to that cold tap. Pain drives action, prompting us to run away, avoid it in the first place, or signal to others that we need help and relief.

How do we feel pain?

Just underneath our skin surface, we have an intricate network of 'pain nerve fibres' that end with special ●



Emotions can amplify pain: people who are nervous at the dentist may have a harder time than more relaxed patients

Capsaicin in chillies binds to heat receptors in your mouth, which is why spicy food burns



receptors called nociceptors. When activated, these receptors send signals along the nerve fibres to the spinal cord and up into the brain, where pain, as a perception, emerges.

The nociceptors can be activated by a variety of triggers: thermal (heat), mechanical (like a knife cut or hammer blow) and chemical/irritant (for example, acid or chilli pepper). The signals then travel along different types of pain nerve fibre. A δ , also known as A-delta, fibres carry what we call 'first pain' – the fast, quick signal that tells you 'ouch' when you touch a hot pan. C fibres follow up with the 'second pain', which is the slow, constant throbbing that tells you it's still hurting. Normal touch – feeling something like your clothes or holding a pen – is carried on different peripheral nerves called AB (A-beta).

The transmission of the pain signal to the spinal cord is helped by other components of the nerve fibres called ion channels, and it's these that many patients with CIP don't have, which is why they don't feel pain. Therefore, targeting and blocking nociceptors and/or the transmission process is a cunning way to block pain. Indeed, that's what many pharmaceutical companies are currently trying to do.

Interestingly, many nociceptors are 'polymodal' – a fancy word meaning

that different things can activate the same nociceptor. As an example, let's look at temperature and food.

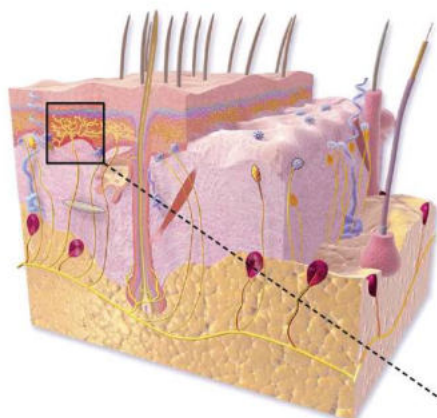
How can food be painful?

Different thermal nociceptors in our body are activated by specific temperatures, giving us a painful sensation of intense hot or cold. Amazingly, these same nociceptors are also activated by various natural chemicals, giving rise to the same experience. For instance, when we bite into a chilli pepper, a chemical called capsaicin binds to the same nociceptor that's activated by painfully hot temperatures of around 42°C and above. That's why we perceive a curry as hot: the brain can't distinguish what activated the nociceptor, it just knows that your mouth is burning! Downing a pint of lager won't help, either, as capsaicin is fat-soluble, not water-soluble – so order a cucumber raita instead.

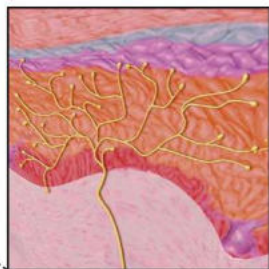
Some scientists think that plants produce capsaicin to discourage mammals from eating their fruits. Birds don't seem to react to the chemical, allowing them to eat the chillies and help with seed dispersal, which is what the plant wants!

How does the brain generate pain?

Once the pain signals arrive from



LEFT: Nerves (yellow) lie beneath the surface of the skin



JARGON BUSTER

CAPSAICIN

This chemical, found in chillies, binds to a nociceptor that also responds to extreme heat. This is why biting into a chilli can cause pain.

NOCICEPTORS

These are receptors on the pain nerve fibres that act like a lock. Certain keys (irritants, mechanical forces, temperature) open them and set off messages to the brain, signalling pain and tissue damage. Over-the-counter painkillers target nociceptive pain.

PAIN NERVE FIBRES

A δ (A-delta) and C fibres are nerves that carry signals from nociceptors in the skin, muscles and joints to the spinal cord.

PHANTOM PAIN

This is the perception of pain in a limb or organ that's missing. This most often occurs following the amputation of an arm or a leg. It's devastating for patients, and some theories suggest that it's a result of altered nerve signals in the brain trying to 'fill the gap'.

PLACEBO ANALGESIA

Placebos are substances with no active therapeutic effect. Patients who take them often report improvements in their condition. Placebo analgesia is pain relief from, say, a sugar pill, and neuroimaging has shown that it can work by hijacking an old and inbuilt 'free pain relief' system in the brain.



Heat



Chemical/acid



Mechanical



Cold

THE PAIN PATHWAY

From the initial trigger to the feeling of 'ouch', the whole process takes only a matter of milliseconds

1. Specialised sensory receptors called nociceptors detect the painful stimulus, converting it into an electrical signal. There are different nociceptors for different stimuli: heat, mechanical, chemical/acid, and cold. Some detect more than one type of stimulus.

2. The signal travels along two types of pain nerve fibre to the spinal cord. A-delta fibres carry the sharp, rapid pain, while C fibres carry the slow, dull ache. Signals are modulated in the spinal cord before being sent to the brain.

3. A network of many brain regions is involved in processing the signal. The perception of pain emerges from this complex activity.



WHAT WE STILL DON'T KNOW

1 HOW WE DETECT A PINPRICK

Using molecular biology and various natural chemicals as 'probes', we've identified most of the nociceptors in the body that respond to painful events. However, we're still missing the nociceptor that detects a painful hammer blow, knife cut or pinprick. Several research groups are on the hunt for this elusive nociceptor.

2 WHY PEOPLE DEVELOP CHRONIC PAIN

In chronic pain, the A-delta and C fibres often switch on permanently, causing non-stop agony. If we can work out why this happens and manage to prevent it, we'll have gone a long way to helping millions of sufferers. Also, we still need to understand why, after the same injury, one person can develop chronic pain, but the other person does not.

3 WHERE THE 'HURT' IS IN PAIN

It's thought that Oscar Wilde once said: "I don't mind pain, so long as it doesn't hurt". Funny, yet spot on. We know that the perception of hurt emerges from a network of brain regions activating together, but we still don't know exactly how this activity produces the 'hurt' of pain. Brain imaging should tell us more...

In one tweet...

Pain, as an alarm, is essential for survival. Chronic pain is bad and millions suffer, but scientific discoveries bring hope.



Pain signals arrive at the brain via the spinal cord

● the spinal cord to the brain, a large network of brain regions is activated, including the brainstem, the thalamus and several regions of the cortex. The subjective experience of pain then emerges from this brain activity.

Until the conscious brain processes these incoming signals, we don't actually call it pain, but nociception – this is the nervous system's response to the original tissue damage. The relationship between the extent of tissue damage and the amount or quality of pain that the person actually *feels* is not a simple one-to-one mapping. Incoming signals can be amplified, attenuated or reappraised by the brain, which can dramatically change the individual's experience. So, being sad about your pain or being anxious at the dentist really will make it worse – emotions are like amplifiers in your brain, turning up the volume of pain.

Thankfully, we also have an inbuilt system to lessen pain. The brain system that's responsible for the feelings of pain can talk to the spinal cord and suppress nociceptive signals, like a brake. This results in less brain activity and less pain, at least until the brake is removed. This is what goes on in athletes and soldiers during situations of high arousal and battle, or when someone is distracted from their pain (for example, a parent desperately distracting their child from the dreaded vaccine jab). It's not a trick, but real physiology. In fact, it's this system, called the 'descending pain modulatory system', that's hijacked when the placebo effect acts to reduce pain. This is known as 'placebo analgesia'.

Weirdly, it was once thought, not too long ago, that because animals and babies have less developed brains than adults, they cannot feel pain. This is complete nonsense. Pain is an individualised and subjective experience that depends upon a person's mood, how much attention they give to it, the context of the situation in which they are hurt and

so on – and it doesn't need a fully-developed brain to take place.

What is the difference between physical and emotional pain?

Historically, if people reported pain in the absence of an injury, it was called 'psychogenic' pain – a pejorative term due to a flawed understanding of the mechanisms involved. Emotional pain also has a neural basis, and there are even overlaps with some brain regions involved in physical pain. Understanding the basis of someone's pain is important if we're going to help them. For example, is the pain due to inputs from the body, or has the brain generated an experience independently? We shouldn't think that physical pain is more 'real' or important than emotional pain.

What is chronic pain?

This is the system gone wrong. It's defined as pain that persists beyond normal tissue healing time.

A staggering one in five adults experiences it. It lasts, on average, for seven years, but for 20 per cent of people it's more than 20 years, and is more prevalent in women and the elderly. Chronic pain wreaks suffering on patients and their families. It also brings significant costs to society, estimated annually at €200bn in Europe and \$600bn in the US. Additional problems like depression, anxiety and sleeplessness can add to the suffering.

Chronic pain is one of the largest health problems worldwide, and current treatment options do not provide adequate relief to the majority of patients. Patients with chronic pain might have different conditions. Nerve damage due to diabetes, being on chemotherapy, multiple sclerosis, sustaining an injury, phantom limb pain, or arthritis, are a few examples. Yet the signs and symptoms that patients describe are often similar. We are starting to consider chronic pain as a disease in its own right,

IN A NUTSHELL

1 NATURE'S ALARM

Pain is essential for survival, alerting us that something is wrong and that we've possibly damaged ourselves. It prompts us into action and is a great teacher – we learn to avoid things that hurt.

2 ALL IN THE BRAIN

Pain emerges from brain activity, but there isn't a simple one-to-one mapping between the amount of tissue damage and the pain we experience. It's a highly subjective phenomenon, and our emotions, attention, expectations, and context can all influence the incoming signals to strengthen or weaken the pain.

3 PROBLEM PAIN

One in five adults experiences pain that persists beyond three to four months from the original injury – the definition of chronic pain. Our understanding of the biology behind this is vastly improving, so there could be new therapies on the horizon.

BELOW:
A patient with multiple sclerosis has their skin sensitivity checked by a neurologist



PHOTOS: SCIENCE PHOTO LIBRARY/ALAMY

Enhanced colour
X-ray of opium poppy pods



with underpinning problems that we can work on and try to fix.

A key problem in chronic pain is that Aδ and C fibres can switch on permanently when damaged, sending constant pain signals to the sufferer's brain. Second, it's been shown that the pathway from nociceptor to brain can get 'sensitised' so that the signals are amplified. This makes the situation worse, causing even the touch of clothing or bedsheets to become painful. Imagine that, but worse, going on for years alongside additional constant pain.

How can we know how much pain someone is in?

It's important to signal when we're in pain because this drives empathy and compassion in others, as well as eliciting help. Generally, we use behavioural observations and language to work out if someone is suffering. People grimace, writhen or cry out in agony. But it's hard to measure pain, as it's such a subjective experience.

If language is available, then rating scales can help to capture features of the pain such as intensity and unpleasantness (0 = no pain, 10 = excruciating). But I doubt your 10 is

my 10. Questionnaires can be used instead of number scales, and sometimes just smiley or sad faces, such as with children. Pain levels of babies, comatose or anaesthetised individuals, or dementia patients may be more difficult to judge, and it's tough to know what they're really feeling. Looking at body measures, like heart or breathing rate, can help. Some studies suggest that women are more sensitive to pain than men, but perhaps women cope better – we all know about man flu! Brain imaging is helping us to understand pain better, but it should not be used as a surrogate for what the person reports. The International Association for the Study of Pain defines pain as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage". In short, if the person says they are in pain, then they are, no matter what caused it.

How do we treat pain?

Painkillers provide relief from pain. The two oldest are aspirin, which is derived from willow bark, and morphine, which comes from opium poppies. These days, aspirin is largely replaced by ibuprofen if there is inflammation, or paracetamol if there is no inflammation. Morphine is an opioid and variants of it are still widely used, but can have associated problems like tolerance and addiction. Other painkillers include different types of anti-inflammatory style drugs, antidepressants, and anticonvulsants. There are many additional treatments for pain, including cognitive behavioural therapy, physiotherapy and surgery, and the most effective therapies combine all of these treatments. With new drugs coming through the pipeline, and our understanding of pain constantly improving, we can hope for a future where no one will have to suffer unnecessary pain. ●

Prof Irene Tracey is head of the Nuffield Department of Clinical Neurosciences at the University of Oxford.

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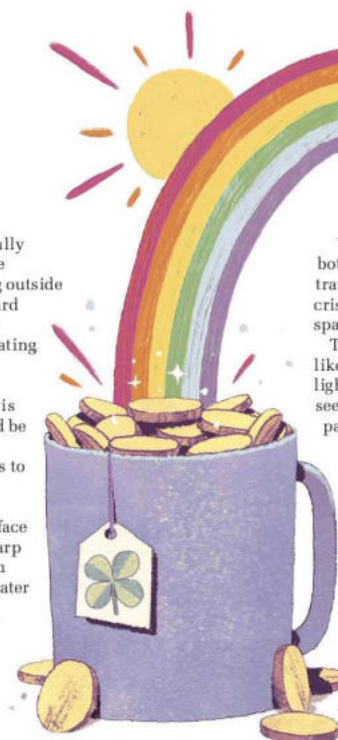
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HELEN CZERSKI ON... **CAUSTICS**

**"THIS MEANS THE POT OF GOLD AT THE END OF
THE RAINBOW IS UNATTAINABLE"**



Proper summer has finally arrived, along with the opportunity for sitting outside and basking like a lizard through long and lazy afternoons. On a sunny day, while eating al fresco, intense sunlight glints off plates and glasses, and the most important question of the afternoon is whether clotted cream or jam should be spread on scones first. But take a moment away from these ponderings to look at the table – really look – and you'll see that it's covered in bright lines and odd dark patches. The surface of your tea is decorated with two sharp semicircles on the side furthest from the Sun. Your transparent glass of water casts a weird dark shadow (even though it is transparent), cut in half with a blaze of white light. Inside the rim of a plate, there are thread-like lines which roll across the surface as you tilt it. All of these features are called caustics, and a sunny day offers the perfect opportunity to admire them.

Caustics are the sharp dividing lines between bright and dark regions, and they turn up wherever parallel light rays meet curved surfaces. Because the Sun is effectively a point source a long way away, the light rays coming from it are almost perfectly parallel. When they reach the inside of a teacup, they bounce off at different angles, depending on which part of the inside of the cup they hit. But there are some regions that many different rays get directed to (those are the bright semicircles) and some regions which are effectively forbidden – they can't be reached by any reflected ray. In your cup, the two intense semicircles meet at a point called the cusp, which makes a distinctive pattern known as a nephroid caustic, because it's vaguely kidney-shaped.

You've probably also seen caustics on the bottom of a swimming pool, where waves travelling across the surface focus light into criss-crossing bands, and direct it away from the spaces in between.

The surface where you see a caustic is acting like a screen, giving you a sneak peek into where light was travelling. If you move the screen, you'll see the pattern change, but the three-dimensional pattern itself was there all along. The light field around us is lumpy and bumpy like this all the time, especially on sunny days. But we need to put an obstacle in the way to make the lumps and bumps visible.

The final stage in the beauty of caustics brings us to the rainbow. Light paths are bent as they cross from one transparent object to the next, violet bends more than red. You may well see some coloured lines in the shadow from your water glass because each colour generates its own caustic, and they don't line up. And so we come to the search for a pot of gold. A rainbow is formed as light from the Sun reflects and refracts its way around the inside of tiny water droplets in the sky.

Afterwards, the light field for each colour is lumpy, with caustics dividing the most and least intense regions. You intercept that pattern with your own eyes, and you see the rainbow – different caustics for red, orange, yellow, green, blue, indigo and violet, glittering in a giant arc across the sky. The lumpy light field exists at every point between you and those water droplets, and your eyes detect the unique pattern at your viewpoint. But this means the pot of gold at the

end of the rainbow is unattainable, because all that's there is a three-dimensional pattern. However, the dish of butter on the table is right here, so maybe I'll admire the caustics inside the dish and make do with that instead. ☛

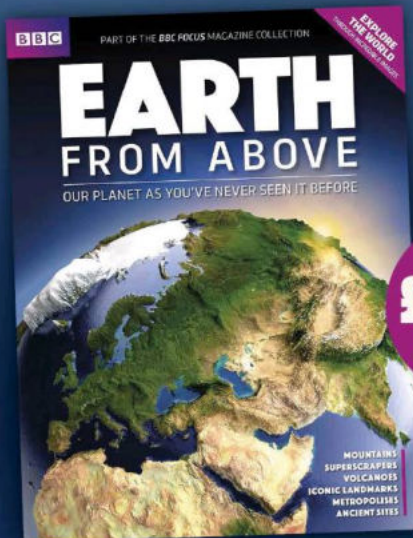
Dr Helen Czerski is a physicist and BBC presenter. Her latest book is *Storm In A Teacup*.
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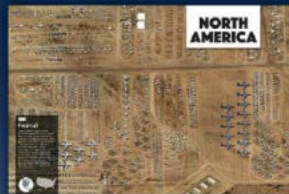
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YOUR QUESTIONS ANSWERED

AUGUST 2017

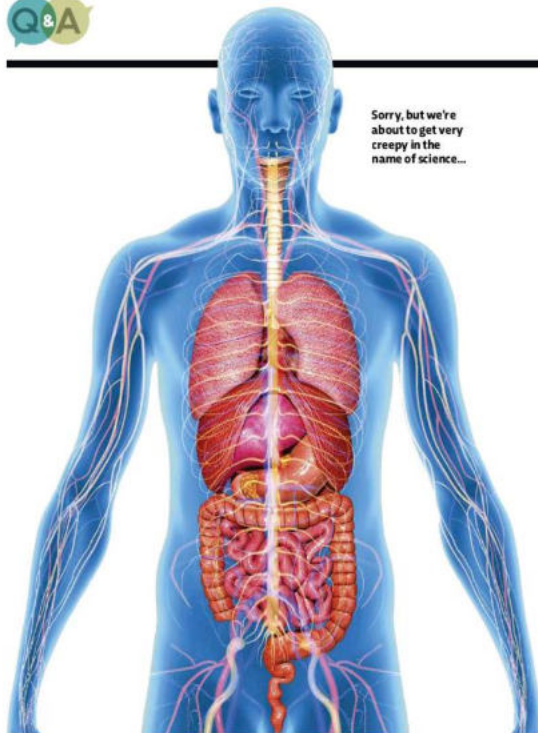
EDITED BY EMMA BAYLEY

Why do rockets follow a parabola after launch?

FRED WILHELM, US

Students have long been taught that all projectiles follow a curved path known as a parabola. The explanation is that as they fly, they cover distance both horizontally and vertically – but only the latter is affected by the force of gravity, which bends the path of the projectile into a parabola. For long-range rockets, things are more complex. For example, air resistance must be taken into account. But even ignoring that, a projectile doesn't really follow a parabola – because the Earth isn't flat. This means that gravity doesn't simply pull objects straight back down. Instead, it pulls them towards the centre of the Earth, whose direction changes as the projectile moves further down-range, away from the launch site. Detailed calculations then reveal that the true trajectory is not a parabola, but part of an ellipse. **AM**

PHOTO: SPACEX



Sorry, but we're about to get very creepy in the name of science...

How many organs could you lose and still live?

ALICIA JONES, MAIDSTONE

You can still have a fairly normal life without one of your lungs, a kidney, your spleen, appendix, gall bladder, adenoids, tonsils, plus some of your lymph nodes, the fibula bones from each leg and six of your ribs. Losing your uterus, ovaries and breasts, or your testicles and prostate, is also quite survivable, although you might need hormone therapy to avoid other long-term problems, such as brittle bones.

If you allow yourself artificial replacements and medication, we can go further and remove your stomach, colon, pancreas, salivary glands, thyroid, bladder and your other kidney. Still not enough for you? Theoretically,

surgeons could amputate all of your limbs, and remove your eyes, nose, ears, larynx, tongue, lower spine and rectum. Supported by machines in an intensive care unit, they could also take away your skull, heart and your remaining lung, at least for a short while.

This adds up to a theoretically survivable loss of around 45 per cent of your total body mass. But any trauma that destroyed all these organs all at once would almost certainly kill you from shock and blood loss. And surgically removing them one at a time over many months would likely also be fatal, due to infections in your immune-compromised state. **LV**

How do we talk in our heads?

BOB LADENDORF, US



Talking in our heads is referred to by psychologists as 'inner speech'. It involves some similar processes to 'overt' speech – it recruits brain regions involved in language, such as the Broca's and Wernicke's areas, and is even accompanied by minute muscle movements in the larynx. However, there are notable differences too, with brain areas useful in inhibiting overt speech playing a greater role in inner speech. The exact brain mechanisms involved may come down to why we are talking in our heads in the first place. For example, when we read a book, brain regions involved in attention may be more active than when we are mentally preparing for a race. **AG**

How do household cleaning products affect the environment?

AMY RHYS-DAVIES, CAMBRIDGE

Even after passing through water treatment plants, small quantities of chemical compounds from cleaning products can find their way into rivers, ponds and lakes and have adverse effects on aquatic life. Phosphates in laundry and dishwasher detergent have a fertilising effect, triggering the widespread growth of algae that saps away the water's oxygen, reducing biodiversity. By reducing water tension, surfactants allow other pollutants in water bodies to be absorbed more easily by plants and animals. Many other compounds can be toxic to wildlife, or affect growth and reproduction, for instance by mimicking the effects of hormones in mammals and fish. **APC**



How is helium turned into a liquid and a superfluid?

TOBY CARTER, BY EMAIL

At -269°C, helium gas condenses to become a liquid. Cool it even further and it becomes a state of matter called a superfluid. In this state it has no measurable viscosity and so does some odd things, such as climbing up the walls of a dish, leaking through apparently solid materials and staying motionless while its container is spun. To create the liquid and superfluid states, you cool down helium gas to a few degrees above absolute zero.

This is achieved by compressing the gas, and then expelling it through a small nozzle. As the gas expands, it rapidly cools (you'll have noticed this effect if you've ever used an aerosol deodorant). The process is repeated until the gas that rushes out of the nozzle is cold enough to condense to a liquid, then if you repeat the cycle a few more times the helium will become cold enough to turn to a superfluid. **ML**



THE THOUGHT EXPERIMENT

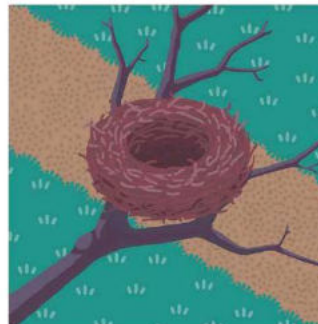


Could you throw a frisbee on Mars?

JONATHAN HINCHLIFFE, BIRMINGHAM

Since the Martian atmosphere is about 100 times less dense than Earth's, the 'lift' a frisbee experiences would also be about 100 times less. But the gravitational force on Mars is about a third of that on Earth, so a frisbee on Mars would act as if it is about 33 times heavier (100/3). Since the lift depends on the size of the frisbee, the angle of attack and the velocity it is thrown (as well as the air density), it would still be possible to make a frisbee glide, but it would require much more effort on the part of the thrower! **AGU**

WHAT WOULD HAPPEN IF ALL EARTH'S INSECTS VANISHED?



1. FOOD CHAIN COLLAPSE

Most non-marine food chains depend on insects. Almost all birds eat insects, and even those that eat seeds as adults still feed insects to their young. It takes 200,000 insects to raise a swallow chick to adulthood. Insects also break down plant matter and help recycle nutrients into the soil. Without any insects at all, most bird and amphibian species would be extinct in two months.



2. NO POLLINATION

Of the world's food crops, 75 per cent are pollinated by insects. Without insects, we could still grow many foods, but onions, cabbage, broccoli, chillies, most varieties of tomato, coffee, cocoa and most fruits would be off the menu. So would sunflower and rapeseed oil. Demand for synthetic fibres would also surge because bees are needed to pollinate both cotton and flax for linen.



3. LESS INSECTICIDE

On the plus side, if there were no longer any insects, we wouldn't need the 430,000 tonnes of insecticides that are sprayed onto crops every year. In the US, pesticide residues cause between 4,000 and 20,000 cases of cancer each year, according to the National Academy of Sciences. But this is a small compensation for total ecological collapse and global famine.

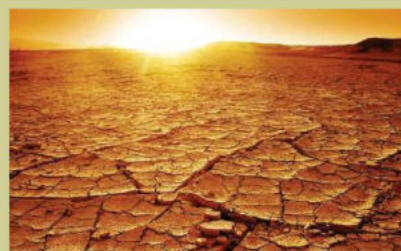
PHOTOS: GETTY IMAGES; ILLUSTRATIONS: RAJALOCKEY

Can the placebo effect harm you?

AMMAR EL-BEIK, BY EMAIL



Just as the placebo effect causes positive results if you believe you are taking beneficial medicine, there is a negative version, called the nocebo effect. This creates harmful effects such as pain, high blood pressure, dizziness and rashes if you believe that these are possible side effects of the medication you have been given, even though it's a placebo. **LV**



How hot could Earth get before it's uninhabitable for humans?

JACOB HIPKISS, SOUTHWELL

Humans need to sweat to survive in warm conditions, and that's only possible if the combination of temperature and humidity – known as the wet-bulb temperature – stays below around 35°C. According to a 2012 study by scientists at MIT, this limit could be reached globally if our planet warms by around 12°C. Fortunately, few scientists think global warming will do this in the foreseeable future. **RM**



How long could you survive on beer alone?

COLIN GRAY, CASTLE CARY

Beer typically has around 40 calories per 100ml (one pint = 568ml). To get your daily 2,000 calories just from beer, you'd need to drink 11 pints every day, which is hardly healthy. But the alcohol is the least of your problems. Beer, even real ale or Guinness, contains no fat, almost no protein and – crucially – no vitamin C. Without any source of vitamin C, you'll experience symptoms of scurvy in two or three months and be dead in six. **LV**



What is being done to preserve Pompeii?

SARAH FOX, AUSTRALIA

The main threat to the already excavated buildings and mosaics is moisture, which attacks the plaster and mortar. But Pompeii has attracted the best archaeological conservationists from around the world. In 2012, a 10-year project began installing protective roofs, removing existing moisture and researching the chemical structure of ancient plasters. There is also a moratorium on new archaeological excavations. **LV**

IN NUMBERS

25

The percentage of the world's population who eat chillies every day.

100

The number of tiny needles embedded into a painless skin patch vaccine that could be used instead of traditional syringes.

6,000

The number of wildebeest that drown during the migration every year.

WHAT HAPPENS IN MY BODY...

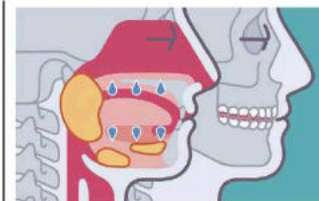
...WHEN I SLEEP?

Sleep consists of two radically different physiological states. There is rapid eye movement sleep (REM) and non-rapid eye movement sleep (NREM). The sleep stages seem to have different functions, but why we sleep is still not completely understood. Babies spend half of their sleep in REM, but this drops to a quarter by the age of two. It is therefore thought that REM sleep is particularly vital for the developing brain. In NREM sleep, brain activity slows and a person woken at this stage may feel groggy.



1. Pituitary gland

During non-REM sleep, the pituitary gland produces growth hormone and secretes prolactin. This counteracts dopamine, to lower general arousal levels.



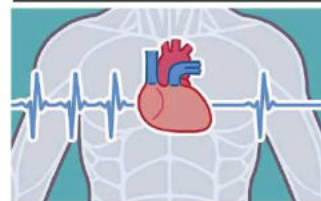
2. Mouth

You produce less saliva, which reduces the need to swallow. Five per cent of adults also grind their teeth at night, mostly during the early stages of sleep.



3. Lungs

The throat muscles relax so your airway narrows when inhaling. This can cause snoring, or temporarily halt your breathing for a few seconds (sleep apnoea).



4. Heart

Your pulse drops by 10-30bpm while you sleep, lowering your blood pressure. Less blood flows to the brain, and more is diverted to your muscles.



5. Limbs

The extra blood swells your arms and legs slightly. Muscles are paralysed while dreaming, but between dreams you change sleeping position 35 times a night.



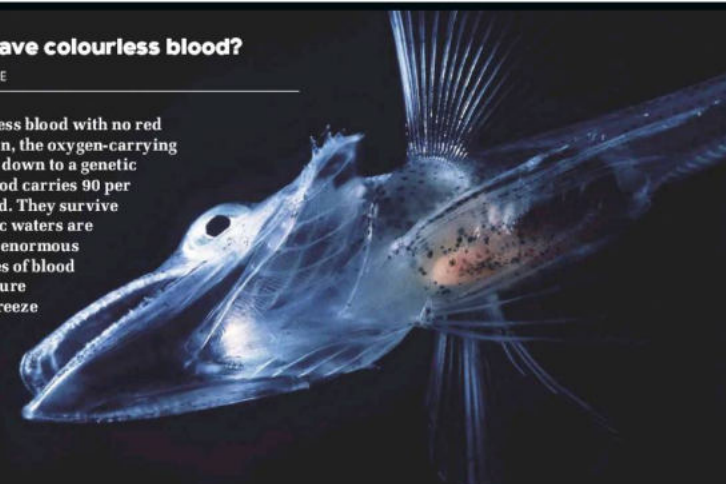
6. Bladder

Vasopressin hormone levels rise. This reduces the amount of urine collected in the bladder to between a half and a third of normal daytime levels.

Why do some fish have colourless blood?

LORELY MASKELL, BUCKINGHAMSHIRE

Antarctic icefish have colourless blood with no red blood cells and no haemoglobin, the oxygen-carrying pigment. This probably comes down to a genetic mutation, and means their blood carries 90 per cent less oxygen than red blood. They survive partly because frigid Antarctic waters are oxygen-rich. Icefish also have enormous hearts that pump huge volumes of blood around their bodies, making sure they get enough oxygen. Antifreeze in their blood stops them from freezing (the salty Southern Ocean gets down to -2°C) but as they are so well-adapted to the cold, their future in a warming world remains uncertain. **MS**





Does holding your breath make you stronger?

PAD SCANLON, LONDON

It won't make you stronger in the sense of building muscle in your heart or diaphragm, but holding your breath while training for certain sports has been shown to improve the ability of your muscles to cope with short, intense exertions. This works by increasing the concentration of bicarbonate in the blood, which helps to neutralise the lactic acid produced during anaerobic exercise. For this technique to work,

you need to exhale normally and hold your breath when your lungs are empty, rather than taking a big breath in and holding that. There are significant risks, though.

A 2009 study found that free divers who regularly held their breath for several minutes had elevated levels of a protein called S100B in their blood, which is an indication of long-term brain damage. **LV**

WHAT'S IN...

...HAND CREAM

There are two ways that hand creams act to moisturise your skin. Occlusive agents form a barrier that traps water, while humectants attract more water to your skin. The problem is that the humectants are water soluble, while the occlusive agents dissolve in oil. So to get them to mix in an easy-to-use formulation, the creams also need an emulsification system. **ML**

WATER 80 per cent

Gives the cream volume and dissolves some ingredients.

GLYCERINE 3 per cent

Is a typical humectant used to draw water in from the atmosphere.

THICKENERS 5 per cent

PEG or polyacrylic acid (which may appear as carbomer on the label) are long polymer molecules that increase the viscosity of the cream, making it easier to apply.



FATS AND OILS 7 per cent

Coconut oil, petroleum jelly or lanolin (a waxy substance secreted by woolly animals such as sheep) might be used as occlusive agents that form a barrier to block escaping water.

EMULSIFIER 2.5 per cent

Glyceryl stearate and stearic acid help to stabilise the oil/water mixture.

PRESERVATIVES AND FRAGRANCE 2.5 per cent

These improve the product's shelf life and make it smell nice.

How do stars die?

LESLIE GRIFFIN, MALVERN

Stars die because they exhaust their nuclear fuel. The events at the end of a star's life depend on its mass. Really massive stars use up their hydrogen fuel quickly, but are hot enough to fuse heavier elements such as helium and carbon. Once there is no fuel left, the star collapses and the outer layers explode as a 'supernova'. What's left over after a supernova explosion is a 'neutron star' – the collapsed core of the star – or, if there's sufficient mass, a black hole.

Average-sized stars (up to about 1.4 times the mass of the Sun) will die less dramatically. As their hydrogen is used up, they swell to become red giants, fusing helium in their cores, before shedding their outer layers, often forming a 'planetary nebula'. The star's core remains as a 'white dwarf', which cools off over billions of years.

The tiniest stars, known as 'red dwarfs', burn their nuclear fuel so slowly that they might live to be 100 billion years old – much older than the current age of the Universe. **AGu**

PHOTOS: ESA/HUBBLE/NASA; GETTY/3; ILLUSTRATIONS: DAVALOCKEY

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If your champagne glasses are grubby, bubbles will form on the specks of dirt, betraying your shoddy washing-up skills

Why do champagne bubbles rise from the bottom of a glass?

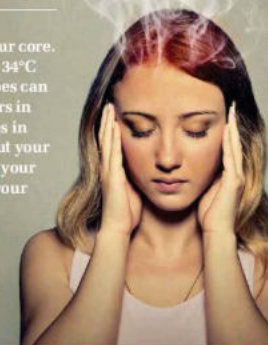
EWAN HAMISH, NOTTINGHAMSHIRE

The bubbles are filled with carbon dioxide (CO_2), a gas 800 times less dense than the surrounding liquid. Molecules of this gas accumulating in imperfections in the glass and start to form a bubble, whose low density supplies enough buoyancy to break off and float towards the surface. In the process they run into more molecules, making the bubble even bigger and more buoyant, and accelerating its ascent. **RM**

Why does 37°C feel so hot when our bodies are at that temperature already?

SIMON LEYLAND, LINCOLN

That's the temperature of your core. Your skin is usually around 34°C and your face, fingers and toes can be much colder. The receptors in your skin react to differences in temperature, so when you put your hand on your bare stomach, your hand registers warmth but your belly shrieks 'cold!', even though both are 'skin temperature'. Similarly, the inside of your mouth feels warm to your finger, but not to your tongue. **LV**



WHO REALLY DISCOVERED?

CRISPR

EMMANUELLE CHARPENTIER
AND JENNIFER DOUDNA

BROAD INSTITUTE

Hailed as the biggest breakthrough in genetic science this century, CRISPR is shorthand for a molecular toolkit that allows scientists to make precise changes to the genetic code of living organisms. Strictly speaking, the acronym stands for 'clustered regularly interspaced short palindromic repeats', a pattern in the DNA of bacteria first noticed by 1987. For years the role of this pattern was mysterious, but in the mid-2000s clues emerged that suggested it was part of the antiviral defence system of bacteria. Studies showed bacteria took sections of a virus's DNA and built it into their own genome using an enzyme codenamed Cas. The resulting CRISPR sequences then allowed the bacteria to detect an attack and fight back. But the key breakthrough came in 2012, when teams in the US and Europe led by Jennifer Doudna and Emmanuelle Charpentier showed how the defence system could be turned into a 'cut and paste' tool for editing gene sequences. However, another US team beat them to a patent for using the method on human cells, sparking a legal row over priority – and last February, the US patent office ruled against Doudna and Charpentier. Despite this, they remain widely credited as the real pioneers of CRISPR by fellow scientists. **RM**

How does physical exercise help reduce stress?

LUCIE COLTMAN, VIA TWITTER

Research clearly shows that physical exercise can reduce stress and anxiety, but it's less clear how this occurs. Multiple mechanisms are likely to be important. Exercise can help to reduce the body's response to stress by boosting serotonin levels in the brain.

It can also give us a sense of achievement and increase our self-esteem, which can provide psychological routes by which to reduce stress. Finally, research shows that exercise taken in moderate amounts and at appropriate times of the day can improve our sleep. Good sleep quality can help us to regulate our emotions and therefore provides another way in which physical exercise helps to reduce stress. **AGr**



Do trees reduce air pollution levels?

ROGER LENTON, SALISBURY

The relationship between trees and air pollution is a complicated one. Particulate matter suspended in polluted air tends to settle onto leaves, and certain gases including nitrogen dioxide (NO_2) are absorbed by leaves' stomata, filtering the air and reducing pollution levels slightly. But trees and other vegetation also restrict airflow in their immediate

vicinity, preventing pollution from being diluted by currents of cleaner air. In particular, tall trees with thick canopies planted alongside busy roads can act like a roof, trapping pockets of polluted air at ground level. To reliably improve air quality, city planners need to give careful consideration to how trees are placed. **AFC**

PHOTOS: WIMPEY/GETTY IMAGES/REUTERS/EVYNE

WHAT IS THIS?



Altering perceptions

This creepy-looking robot, called Alter, was designed by scientists in Japan. The robot is connected up to electronic sensors that detect minute changes in the environment. These differences in temperature, humidity or other elements will influence the robot's movements, which are controlled by a brain-like neural network without any input from humans.



Do seagulls drink seawater? And if so, how do they deal with the salt?

SIMON HARVEY, VIA TWITTER

All seabirds drink seawater – yet birds have less efficient kidneys than mammals, and so excess salt is even more toxic to them than to us. Seabirds cope with this by using specialised salt glands next to their eye sockets.

These look like miniature kidneys and work in a similar way, pumping salt ions out of the bloodstream against the normal flow of osmosis. The extra-salty water drips down the side of their beak. **LV**

What is the biggest a moon can be in relation to its mother planet?

EDWARD SEYMOUR, HOVE

A 'moon' is an astronomical body that orbits a planet; the definition doesn't involve size. So, a 'moon' could be a small rock or it could be as large as its 'parent'. However, similar-sized objects orbiting each other are normally called 'double' (for example, Pluto-Charon is often considered a 'double dwarf planet').

But the distinction between 'double' and 'parent-moon' systems is not officially defined. Some astronomers define a 'parent-moon' system as one that has the point about which both objects orbit (the barycenter) inside the larger object, but this distinction is quite arbitrary because it depends on both size and separation. **AGW**



WHAT CONNECTS...

...FROGS AND FRESH MILK?

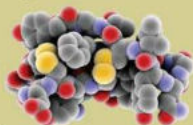


1.

Frogs, like all amphibians, have thin, porous skin that they can breathe through. But this also poses a risk because it makes it easier for bacteria to infect them.

2.

To protect themselves, frogs secrete substances called cationic antimicrobial peptides (CAMPs). Other animals secrete CAMPs too, but frogs produce much more, including some peptides that are effective against multi-resistant bacteria.



3.



Milk goes off because of bacteria, especially species of *Lactobacilli* and *Pseudomonas*. These ferment the lactose in milk into lactic acid, and hydrolyse milk proteins into various unpleasant tasting by-products.

4.

According to Russian folklore, putting a live frog in milk would help it stay fresh. Recent research has found that CAMPs from the Russian brown frog could kill the bacteria in milk and prevent it from turning.

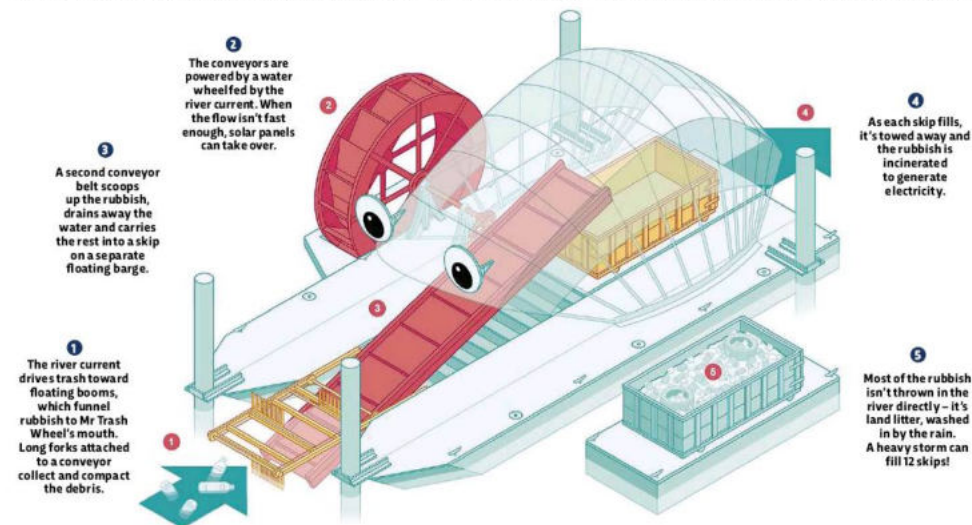


PHOTOS: GETTY IMAGES; SCIENCE PHOTO LIBRARY; SHUTTERSTOCK; ILLUSTRATIONS: RAJA LOCKEY

HOW IT WORKS

MR TRASH WHEEL

At the mouth of the Jones Falls River, where it feeds into Baltimore Harbour in the US, sits Mr Trash Wheel. Since 2014, this semi-autonomous floating rubbish collector has scooped up more than 500 tonnes of detritus, including 9,000,000 cigarette butts, 492,000 coffee cups and 376,000 crisp packets. Mr Trash Wheel cost \$720,000 (£560,000) to build, and has now been joined by Professor Trash Wheel, a 'female' version in a different part of the harbour.



QUESTION OF THE MONTH

Do all fish and shellfish contain mercury?

JACK MOORE, FROME

Mercury levels in the oceans have tripled since the Industrial Revolution, thanks to mining and the burning of fossil fuels. All sea creatures absorb some of this heavy metal directly, and once it's in the body there's no way of getting rid of it. The amount of mercury in fish varies between species. Long-lived predators like tuna and swordfish tend to contain the most, because they also absorb mercury from their prey and they've had a long time to accumulate it. The lowest levels are found in short-lived species lower down the food chain, such as oysters and shrimp. **MS**

WINNER!

Jack Moore wins a pair of Groove-e's new Action Earphones (£44.99, groove-e.co.uk). Held in position around your neck with a bright LED neckband, the stylish earphones are designed to make you stand out and be seen, improving safety for runners at night.



NEXT ISSUE:

Can birds fly upside-down?

What causes eczema?

Do dogs have a concept of time?

Email your questions to questions@sciencefocus.com or submit online at sciencefocus.com/qanda

OUT THERE

WHAT WE CAN'T WAIT TO DO THIS MONTH

AUGUST 2017

EDITED BY JAMES LLOYD



PHOTO: BBC

01 CLIMB ABOVE THE CLOUDS

**MOUNTAIN: LIFE AT
THE EXTREMES**
BBC TWO, AUGUST
(SEE RADIO TIMES.COM FOR DETAILS)

Put on your walking boots and crack out the Kendal Mint Cake! A new three-part series from the BBC's Natural History Unit takes us into the heart of three of the most iconic mountain ranges on our planet: the Rockies in North America, the Himalayas in Asia and the Andes in South America.

Mountain: Life At The Extreme shines a light on the people and animals that thrive at great heights. In the Rockies, we meet the elusive wolverine, migrating rufous hummingbirds, tiny cannibalistic salamanders

and a daredevil wingsuit flier who leaps from mile-high cliffs, while the spectacular footage of the Himalayas includes India's arid Nubra Valley (pictured here) and Everest itself, where a hardy few take on the world's highest-altitude marathon. Finally, in the Andes, look out for some hardy salt-flat lizards that somehow manage to survive in the world's driest desert, the incredible shape-shifting rainfrog, and a Peruvian bus journey that ought to come with a change of underwear.

02 EXPERIENCE PSYCHOSIS

HELLBLADE: SENUA'S SACRIFICE
PS4/PC
OUT 8 AUGUST

New video game *Hellblade* follows the story of Senua, a traumatised Celtic warrior who is on a quest to save her lover's soul from the underworld. Senua experiences frequent hallucinations and delusions during her journey, all symptoms of psychosis – a condition that the game's developers Ninja Theory were keen to portray as accurately as possible.

Hellblade has received funding from the Wellcome Trust, and its creators have been working closely with Prof Paul Fletcher, a neuroscientist and psychosis expert at the University of Cambridge. We spoke to Fletcher and *Hellblade*'s creative director Tameem Antoniades about how they went about representing mental illness onscreen.

Who is Senua and what is her story?

TA: Senua is a Celtic warrior from the late 8th Century whose Orkney homeland has been invaded by the Vikings. They've sacrificed her lover to the Norse gods and so she

sets off on a quest to Hel, the Viking underworld, to retrieve his soul and lay him to rest. During the game, Senua experiences visions, voices and delusional beliefs – symptoms of what we now call psychosis.

How does Senua's psychosis fit in with her backstory?

PF: To some extent, Senua has always seen the world differently from others, but the idea is that the profound trauma she's experienced has triggered these symptoms. Because of her experiences, Senua has lost touch with the reality of those around her. That's really the formal definition of psychosis. We're all more or less prone to psychosis, depending on how we view and experience the world, but trauma can often act as a trigger.

How did the latest research and thinking around psychosis feed into the game's development?

PF: We wanted to represent symptoms such as voice-hearing

and hallucinations, but also to go below the surface and explore what we know about normal perception. We all tend to think that we have a clear representation of reality, but most of the time our minds are actually making it up, deciding what *should* be there rather than what *is* there. It's a kind of controlled hallucination. This idea, too, is deeply embedded in the game: the player becomes sensitive to the visual clues and illusions around them as they progress through the world.

Psychosis used to be thought of as this extreme phenomenon that was completely separate from the normal experience of the world. But we are coming to realise that there's a continuum, and all of us are prone to becoming separate from reality. Hopefully this game will help to demonstrate that.

How did you represent such internal and subjective experiences onscreen?

TA: Throughout her journey, Senua hears her internal chatter as

The portrayal of Senua's psychosis is based on solid science

voices, and so the player hears these too. The voices take on different characters, which are sometimes harsh and berating, sometimes friendly and helpful. We worked closely with a group of voice-hearers to try and get these sounding as realistic as possible.

She also experiences flashbacks as visual hallucinations, and there are subtle changes in the game's environment as she moves around, based on people's descriptions of how delusions manifest in real life. So trees might shift position slightly, or you might see a hidden pattern in a shadow or a reflection. It's these patterns that the player needs to find in order to progress in the game.

What else do you hope to achieve with the game?

TA: First and foremost, it was about creating a compelling, adult, fantasy game. But the deeper we've gone into development, the more we've seen that there's also an opportunity to raise awareness of psychosis. For my part, I've learnt

that people can experience hallucinations and delusional beliefs without it being a problem – the illness comes when those experiences cause suffering. Often the recovery is not about curing yourself of hallucinations, but finding ways to live with them. That was a revelation to me.

PF: It's been refreshing to see a representation of psychosis in which the person isn't just a sort of passive receptacle for madness. Senua is the hero of her own story, trying to make sense of her experiences and work her way through them – that's incredibly de-stigmatising.

In representations of mental illness onscreen, you usually have the illness first, and then a two-dimensional character attached to that. In this case, the character is fully-formed, and they are not defined by their condition. It's been exciting to see Senua received so positively by those who have lived with experiences of psychosis.

THREE MORE GAMES OUT THIS MONTH



TACOMA
PC/XBOX ONE
(2 AUGUST)

Tacoma is the latest release from Fullbright, makers of the critically-acclaimed *Gone Home*. *Tacoma* is a narrative adventure set in an abandoned space station 200,000 miles from Earth. Its crew of six have been evacuated in mysterious circumstances, and it's your job to piece together exactly what happened.



SONIC MANIA
PS4/PC/XBOX ONE/
NINTENDO SWITCH
(15 AUGUST)

Welcome back, O blue one! Sonic the Hedgehog returns in full 2D, pixelated glory with this homage to the Sega games of yore. There are reimagined levels from the iconic titles of the 1990s, as well as entirely new zones and bosses, plus a welcome return for Tails and Knuckles.



UNCHARTED: THE LOST LEGACY
PS4
(22 AUGUST)

Uncharted 4: A Thief's End was many critics' game of 2016. This standalone expansion, set six months after the main game, follows new protagonist Chloe Frazer as she explores the southern tip of India in search of a priceless relic. Expect a typically cinematic treat from developers Naughty Dog.

03 MEET THE QUACKS

QUACKS
BBC TWO, AUGUST
(SEE RADIOTIMES.COM
FOR DETAILS)

You wouldn't want to be treated by this lot. Inspired by real-life Victorian doctors, *Quacks* is a new six-part comedy set in the medical milieu of 1840s London. Created by James Wood, *Quacks* stars Rory Kinnear as a showman surgeon, Mathew Baynton as a fledgling psychiatrist, Tom Basden as a hedonistic dentist, and Lydia Leonard as a social campaigner who's fighting against the medical patriarchy. Ross MacFarlane, one of the show's advisors at the Wellcome Collection, reveals some of the stranger-than-fiction stories that inspired the series...

HUMAN GUINEA PIGS

Doctors in the 1840s were looking for new ways to numb pain. Chloroform was one of the candidate anaesthetics, and in 1847, Scottish physician James Young Simpson and two friends tried it out after a dinner party. The three of them were found passed out – but happily, still alive – on Simpson's drawing room floor the next morning.

SOMETHING FOR THE PAIN?

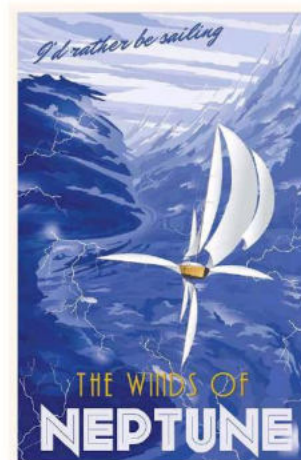
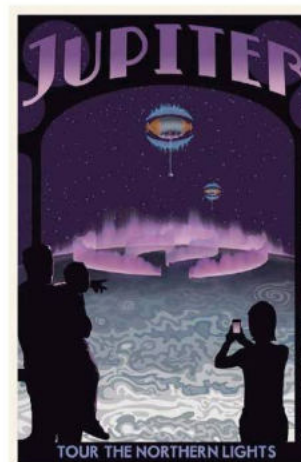
Potent drugs were easy to get hold of in the 1840s. Laudanum, a tincture of opium that's today rated as a Class A substance, could be bought over the counter for anything from childbirth to a mild cough, while diluted versions were even available for children. Thank goodness for Calpol...

NO SCRUBS

Forget about squeaky-clean surgical clothing: Victorian doctors worked in their finest garb. Think tight dress shirts, cravats and some extravagant hairstyles. They'd at least take their jacket off, though. Scrubs didn't come along until the following century, as scientists became increasingly aware of the link between germs and disease.

LOOK INTO MY EYES

John Elliotson, professor of medicine at University College Hospital, used 'mesmerism' as a form of pain relief. The technique, similar to hypnotism, was decryied by many other doctors, notably in an 1842 article accusing him of placing mesmerised female patients in 'curious postures'.



04 SOJOURN IN SPACE

THE VACATION GUIDE TO THE SOLAR SYSTEM
BY OLIVIA KOSKI & JANA GRACEVICH
OUT 3 AUGUST (£19.99, SQUARE PEG).

You know where we really want to go on our holidays? Outer space, that's where we want to go. Just imagine taking an airship through Venus's lemon-yellow clouds, or enjoying breakfast while looking out onto Saturn's swirling, hexagonal vortex! It's hard to see how Marbella or Lanzarote could possibly compete.

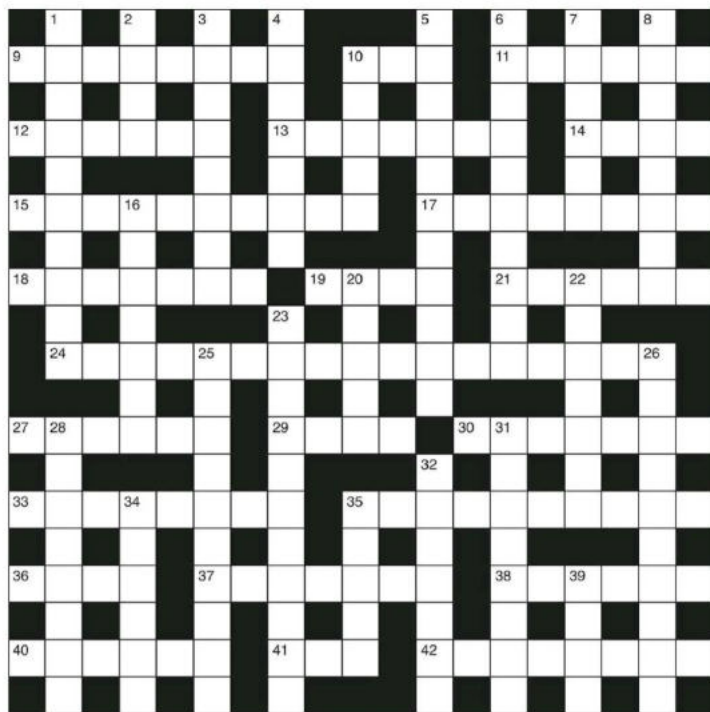
But of course, any budding space tourist will need a guide book. Luckily, *The Vacation Guide To*

The Solar System is packed full of advice on where to go, what to pack, and what to do while you're there. Featuring beautiful retro-inspired illustrations by Steve Thomas, the book's certainly a tongue-in-cheek affair, but the descriptions of the various destinations are all rooted in sound science. With human spaceflight back in the public eye, maybe it's time to swap those shorts and sarongs for a spacesuit.

PHOTOS: BBC, STEVE THOMAS

BBC FOCUS CROSSWORD

GIVE YOUR BRAIN A WORKOUT



ACROSS

- 9 Family cites new science (8)
 10 Broadcasting system becomes a friend (3)
 11 Alternatively, youngster left out a bloomer (6)
 12 Constructing cot, worker made part of a circle (6)
 13 Male feline gets caught in tuba (7)
 14 Flutes surrounding another instrument (4)
 15 Spinning machine created cute fringe (10)
 17 Telling family member (8)
 18 Secrecy of some bombers (7)
 19 Details of his pectorals (4)
 21 Argonaut takes gold home first (6)
 24 Treatment – that takes me back (10,7)
 27 Miniature old basin gets thrown around (6)
 29 Air Force has time for simple vessel (4)

- 30 Everything in grey displayed in exhibition hall (7)
 33 Anglo-Saxon prince hating to work with the Spanish (8)
 35 Group of children have share of genetic material (10)
 36 Old country is different in the morning (4)
 37 Sailor, unaccompanied, finds shell (7)
 38 Percussion instrument reportedly has character (6)
 40 First appeared to have energy round island (6)
 41 Chap takes turn to acquire colour (3)
 42 Igloo yet affecting cause of disease (8)

DOWN

- 1 Gain city a large bottle (10)
 2 Iron, thanks to cheese (4)
 3 Line travelled in London area (8)
 4 Solved this sum to get a bit of land (7)
 5 The excitement of a charged current (11)
 6 Heron flying with combination to find dark amphibole (10)
 7 Old church has a great deal for cat (6)
 8 Endless goodness shown by huge round master (8)
 10 Bean shows sign of life (5)
 16 Used as great crowd disperser (4,3)
 20 Evidence of alcohol (5)
 22 Superficial, swapping end bulb (7)
 23 Hags portray new mapping of the heavens (11)
 25 Menial trio running someone's last race (10)
 26 New boy has a right to give thug a hand (10)
 28 Thor-shaped image in camera tube (8)
 31 Poem that's initially meaningful (8)
 32 A number turn it green (7)
 34 Miner wore European fur (6)
 35 German left awed to the world (5)
 39 Defraud out of a drink (4)

ANSWERS

For the answers, visit bit.ly/BBCFocusCW. Please be aware the website address is case-sensitive.

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"Indiana Jones and I have different policies on artefact acquisition. I try to avoid any sort of death trap"

Archaeologist **Brenna Hassett** talks to **Helen Pilcher** about her adventures, and wonders whether cities will be the making – or the death – of us

What do you do?

I dig up dead people and study their teeth and bones so I can work out what their lives were like.

An archaeologist, eh? How like Indiana Jones are you?

Indiana Jones and I have different policies on artefact acquisition. I go with the systematic, planned scientific excavation and generally try to avoid any sort of death trap. The travel and the worrying choice of clothing are, however, accurate. Hats are critical. I cannot stress how important hats are.

Ever found a 'Lost Ark'?

No, but I have found lots of cool stuff. I once found an Aladdin-style, ceramic lamp on a remote Greek island. At the time, I had no idea of its age or origins. I later learned it was a pilgrim's lamp that had been made in the Holy Land during the 6th Century.

Where have you worked?

I've done archaeological surveys in Greece, which involves walking in straight lines for unreasonable amounts of time in unreasonable amounts of heat, staring at the ground looking for artefacts. I worked on the workers who built the pyramids at Giza. I've studied the teeth of children who lived in London 500 years ago, and I've investigated the remains of people who lived in early Turkish settlements 10,000 years ago.

Tell me something clever that you've learned...

We've made major changes to our species in the 15,000 years since humans went from being hunter-gatherers to a settled society. Our rapid evolution into an urban species has affected our bodies and health. Urban living has led to disease and dental decay. Cities created inequality because when you get so many people living together, someone always appoints themselves manager. City life is killing us.

Should we ban cities?

No. Cities create problems but they're also the place where solutions are born. Cities are bastions of progressive thought. I live in a city. I'm 'Team City'.

Has your work ever got you in trouble?

I once did an archaeological survey in Thailand. I was walking through a banana plantation when I got attacked by fire ants. They drop out of the trees, get under your



clothes and start biting. Shortly after that, I learned it's inappropriate to run screaming, taking off your clothes in front of a Buddhist monastery.

So can anyone do archaeology?

That's a great thing about it. Archaeology surfaces any place where land is disturbed. Look in the flowerbeds in St James's Park in London, or anywhere people have lived in the last 300 years, and you're highly likely to find artefacts, like little clay pipe stems. They're the cigarette butts of the early modern era!

Dr Brenna Hassett is an archaeologist. Her book *Built On Bones: 15,000 Years Of Urban Life And Death* (£14.99, Bloomsbury) is out now.

DISCOVER MORE

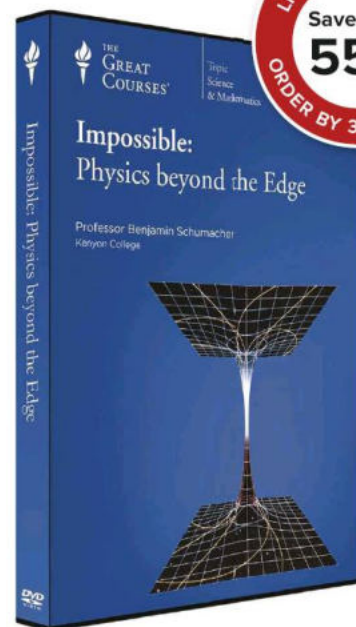
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